THE PROBLEMATIC ASPECTS OF ENERGY EFFICIENCY '22

EDITORS
MACIEJ ZAJKOWSKI • ZBIGNIEW SOŁJAN

Politechnika Białostocka

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Introduction

Energy efficiency is not only energy yield related to the energy consumption in a specific device or building but also the possibility of optimal use of the stored energy in a determine area or in the system, without the necessity for its transmission. Generation, distribution and balancing of energy demand, in a limited area, becomes an energy cluster in which, under the agreement of the entities forming the cluster, there is a possibility for effective management of energy produced and its storage, according to the requirements and assumptions of the capacity market.

The purpose of such an initiative is primarily the effective development of distributed energy, which does not have to be based solely on renewable energy sources, but can also use conventional sources, according to dedicated management models. The whole project is intended to improve energy security, have a positive impact on the environment, strengthen the local economy and generate lower costs for the end user.

According to the RES Act, a member of an energy cluster can be an enterprise, a natural person, a local government unit and their organizational units. It can also include small, medium and large public transport companies and other entities functioning in the area covered by the energy cluster. A cluster initiative may be established and operate in an area no larger than five municipalities or one county, and its purpose is to obtain financial and non-financial benefits for the members of the energy cluster.

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Chapter 1
The influence of reinforcement on the distribution of electric field intensity

Agnieszka Choroszucho
Bialystok University of Technology, Faculty of Electrical Engineering

Abstract: The aim of this paper is to analyze the distribution of a high frequency electromagnetic field (f = 2.4 GHz) inside the living room. The influence of the building material and the diameter of reinforcement on the distribution of the electromagnetic field was shown. The finite-difference time-domain method (FDTD) was used for analysis. The results prove that mounting transmitters on walls with no reinforcement enables an even distribution of the electromagnetic field. The diameter of the rods influences merely the distribution of the field and its value only at a distance of 4 m. A detailed analysis of influence of the type of building construction will make it possible to solve the problem connected with fading.

Keywords: wireless communication systems, electromagnetic wave propagation, building materials, finite difference time domain method (FDTD).

Introduction

The rapid development of radio communication systems enforces the use of electromagnetic waves at constantly increasing frequencies. Their use in, among others, radiolocation, radio communications and satellite communication causes a number of transmitters to grow exponentially [1, 11]. With higher frequencies this growth is more dynamic due to the introduction of wireless communication. The analysis of wave propagation at high frequencies entails the necessity to research the phenomenon connected with the effects that electromagnetic fields have in interaction with materials of different properties. The use of modern-day systems of wireless communication requires taking into account these effects which may lower the effectiveness of data transmission. Such phenomena as diffraction or interference are the subject of various research which aim to determine the distribution of the field's intensity in the discussed settings as precisely as possible. The analysis of fields used in wireless communication systems also requires considering the effects connected with multiple refractions, deflections and damping of waves in areas of different material construction. The mentioned effects are a direct result of wave propagation in structures containing metal elements or constructed of non-ideal dielectrics. They contain complex settings, with periodic structures and singular, non-typical elements with unique material properties and non-typical geometry. Such situations require including resistance of the wireless communication channel to disruptions, interference from neighboring base units, signal delays, periodic damping and loss of signal. Some of these factors are random occurrences, connected with changes in the conditions of wave propagation. However, the construction of a resistant and reliable wireless communication network requires including all the known factors that influence field distribution as early as in the design stages (geometry and construction of buildings, complex material structures in the path between the signal emitter and the base unit etc.). The mentioned problems are especially visible in low range wireless networks (Wi-Fi), used in buildings. Taking into account the construction of both new and already existing buildings influences the location of signal units [13]. The analysis of the field's distribution done in such a way allows to determine the minimal value of the base unit's power, which will enable constant connectivity between the base and mobile appliances. However, these ranges are generalized and have a wide span, for example at 900 MHz frequency, and the damping of the building has values from 37dB to –8dB [1].

The aim of this research is to determine the distribution of the EM field in constructions made of concrete, including various sizes of reinforcement. The results will allow in the future to solve problems connected with signal loss and design optimal locations of a field source within complex reinforced constructions. The article presents the analysis of the properties of materials used in constructing accommodation spaces.

Mathematical model (FDTD)

To determine the distribution of the EM field in the analyzed settings, the finite difference time domain method (FDTD) was used [10]. The method is based on Maxwell's curl equations in time and space:

$$\nabla \times \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t}, \tag{1.1}$$

$$\nabla \times \vec{H} = \sigma \vec{E} + \varepsilon \frac{\partial \vec{E}}{\partial t}, \tag{1.2}$$

which are then transformed into their differentia form. The equations are solved simultaneously in time and space.

The FDTD method allows the analysis of complex structures, in which every material has a corresponding material property, which directly influences the correctness of the results. In order to obtain a simultaneous scalar equation describing individual components of the field, the equations (1)–(2) are subjected to decomposition in the Cartesian coordinate system. As an example, the equation for the EM field intensity component (E_z) in its scalar form is:

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z\right). \tag{1.3}$$

With three-dimensional issues, in a classic formulation of the method, the Yee cell is used (Fig. 1.1) [2]. It contains six appropriately placed component vectors of field intensity: electrical (E_x, E_y, E_z) and magnetic (H_x, H_y, H_z). The use of the FDTD method is based on the division of the whole analyzed area into an appropriate number of cells.

The difference schematic in the area is realized through the proper distribution of component vectors of intensity of the electrical **E** and magnetic field **H** within each cell (Fig. 1.1). The components of the EM field are calculated at a different point in space. The vectors E_x, E_y, E_z associated with the Yee cell are anchored in mid-points of appropriate edges, and the H_x, H_y, H_z vectors – in the middle of the planes forming the sides of the cell. Appropriate component intensity vectors of the magnetic field circulating around it surround each component intensity vector of the electrical field. In the case of component intensity vectors of the magnetic field the presentation is analogical.

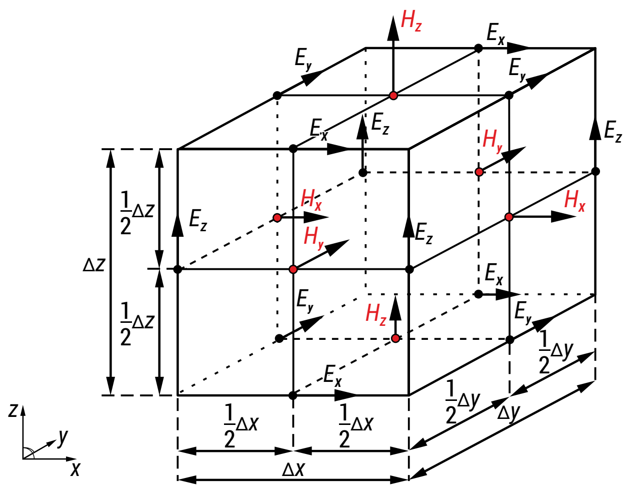

FIGURE 1.1. A single Yee cell in the FDTD method

The integration of Maxwell equations in time is based on using the two-step schematic. In selected moments in time, in which the distribution of the electrical field is determined, the compound vector values of the intensity of the magnetic field are moved in time by $\Delta t/2$ in relevance to them. The determining of compound intensity vectors of the electrical field E_x, E_y, E_z is possible with the prior calculation of the compound intensity vectors of the magnetic field H_x, H_y, H_z in the previous time step of the algorithm. Using the already calculated values H_x, H_y, H_z, the next values of the compound vectors of the electric field are determined E_x, E_y, E_z. The described series of steps is called the time jump process (Fig. 1.2).

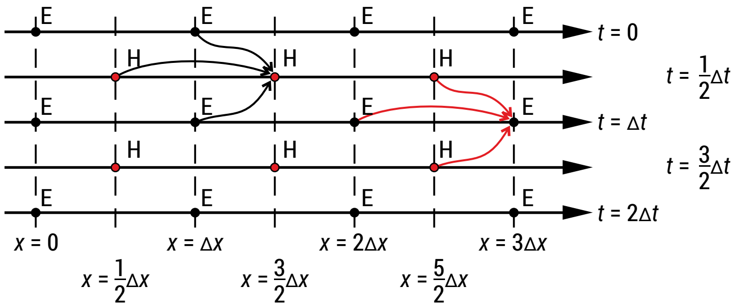

FIGURE 1.2. **Calculating the values of electric and magnetic fields' intensity in the FDTD algorithm**

Another advantage of the algorithm is the assumption that the size of the Yee cell is determined by growth in the Δ space. In a three-dimensional case, if assumed that the Yee cell is a cube, where $\Delta = \Delta x = \Delta y = \Delta z$, then the distances between the appropriate intensity compounds of the electrical and magnetic field are 0.5Δ. Depending on the calculation requirements, the elementary Yee cell after previous modification of difference equations may be cuboid in shape, where $\Delta x^1 \Delta y^1 \Delta z$.

As a result of the approximation of partial derivatives, the Maxwell equation is acquired in a difference form. Therefore, the equation (3) is:

$$\frac{{}_{i,j,k}^{n+1}E_z - {}_{i,j,k}^{n}E_z}{\Delta_t} = \frac{1}{\varepsilon_{i,j,k}} \left(\begin{array}{l} \dfrac{{}_{i+\frac{1}{2},j,k}^{n+\frac{1}{2}}H_y - {}_{i-\frac{1}{2},j,k}^{n+\frac{1}{2}}H_y}{\Delta_x} - \\ - \dfrac{{}_{i,j+\frac{1}{2},k}^{n+\frac{1}{2}}H_x - {}_{i,j-\frac{1}{2},k}^{n+\frac{1}{2}}H_x}{\Delta_y} - \\ -\sigma_{i,j,k}\, {}_{i,j,k}^{n+\frac{1}{2}}E_z \end{array} \right), \tag{1.4}$$

which after transformations allows to determine the compound value along the *x* axis of the electrical field's intensity at the point of observation (i, j+1/2, k+1/2) in time (n+1/2), based on the calculated compounds of the electromagnetic field in the previous moments *t,* at appropriate points in space [14].

Due to the simple formulation of the method and easy imaging of the geometry of the analyzed set, it is especially useful in calculating electromagnetic fields changing in time, in the range of high frequencies and broadband signals.

Numerical analysis

The distribution of the electromagnetic field in rooms containing concrete elements was determined, and introduced without changes in geometry reinforcement in supporting walls (top and left) and the post (in Fig. 1.3 marked in grey). In order to compare the effect of reinforcement on the distribution of the electromagnetic field, different diameters of reinforcing rods were analyzed.

The first model (M1) was created from concrete constructs with no reinforcement according to the existing design (Figs. 1.3, 1.4).

In order to compare the distribution of the electromagnetic field with the inclusion of refractions from rods in the top and left wall and the post, M2 was designed. The top element of 3.2 m in length consisted of: 4 rods running lengthwise with Φ = 8 mm and a concrete cover of 20 mm and rods placed every 200 mm with two rows of 16 vertical rods on either side of the wall (Φ = 8 mm), spaced every 200 mm and a concrete cover of 20 mm (including the starting distance of 40 mm) and two rows of anchoring loops with 16 horizontal rods connecting the vertical rods (Φ = 8 mm) at a height of 200 and 400 mm, spaced every 200 mm (Fig. 5).

Another reinforced element was the left wall of 4.9 m in length: 4 rods running lengthwise (Φ = 8 mm) with concrete thickness of 20 mm (from the outside edge to the reinforcement), spaced every 200 mm, two rows of 25 vertical rods Φ = 8 mm on either side of the wall spaced every 200 mm and a concrete cover of 20 mm (including the starting distance of 40 mm), two rows of anchor loops of 25 horizontal rods Φ = 8 mm connecting the vertical rods at the same height and spaced as in the top wall (Fig. 1.3).

Additionally, within the post there was introduced reinforcement of eight vertical rods Φ = 20 mm in diameter with concrete cover of 40 mm and 5 stirrups Φ = 8 mm spaced every 100 mm, including the distance from the ground of 50 mm (Figs. 1.3, 1.4).

The third model (M3) was based on the construction of M2 with modifications to the rods' diameter (from Φ = 8 to Φ = 12 mm). The post construction remained unchanged.

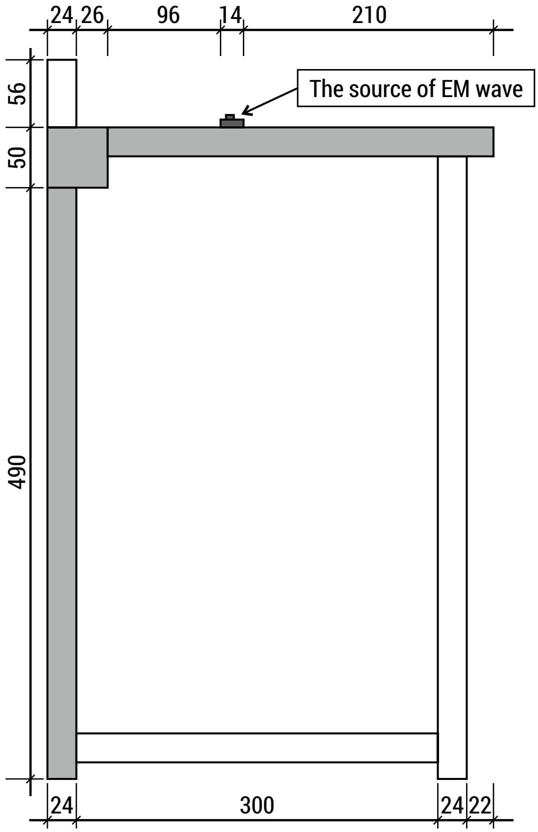

FIGURE 1.3. Geometry of the analyzed room (dimensions in cm)

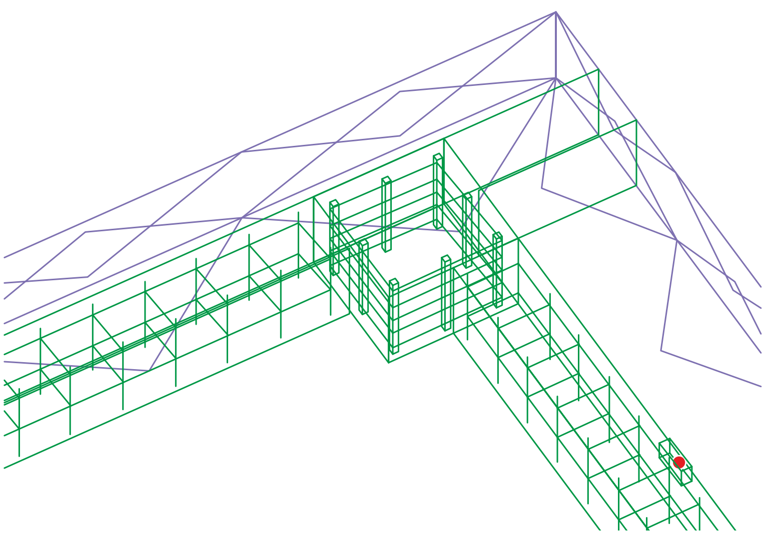

FIGURE 1.4. Reinforcement in the post, top and left wall with absorption conditions

An important topic with the numerical methods is stability. An appropriate choice of parameters of the difference schematic (in time Δt and space Δx, Δy, Δz) is decisive in the stability of the FDTD method, as well as the preciseness of the solutions. The Courant-Friedrichs-Lewy (CFL) condition determines dependency between the minimal value of a time step Δt and the biggest size of the Yee cell (Δx, Δy, Δz) [9, 10]. The stability criterion for a three-dimensional Yee cell is described with the following equation:

$$\Delta t \leq \frac{1}{c_0\sqrt{\frac{1}{(\Delta x)^2}+\frac{1}{(\Delta y)^2}+\frac{1}{(\Delta z)^2}}} \tag{1.5}$$

In the FDTD algorithm the presented criterion is fulfilled on the condition that the spreading speed of the disturbance (change of field value) is greater or equal to the speed of the wave.

An important factor is the correct recreation of the intended signal. In order to eliminate such mistakes, the Nyquist criterion is used [3, 4, 6]. In practice, it is assumed that the biggest step in space (Δx, Δy, Δz) should be at least ten times smaller than the length of the wave λ [6]:

$$\max(\Delta x, \Delta y, \Delta z) \leq \lambda / 10. \tag{1.6}$$

In the analyzed sets, the source of the signal was a dipole generating a harmonic wave with the frequency of 2.4 GHz. The condition (6) has been fulfilled because a net of cubic elements 10´10´10 mm was assumed.

When solving this type of tasks, it is necessary to limit the area of analysis. Boundary conditions properly represent physical effects at the edges of the analyzed area and are necessary for the numerical solution of field tasks. In the discussed sets, Mur's absorption conditions of the first order were used [4, 5].

The conducted calculations analyzed only the influence of the used building material and reinforcement on the distribution of the field in a given room. Relating to the above statement, refractions and reflections of the EM wave from the ceiling were not taken into account. Absorption conditions were used also on its top and bottom surfaces. The size of the analyzed numerical model was approximately composed of 4 612 416 Yee cells.

All elements of the construction had material data of standard concrete assigned to them. The permittivity was assumed at $\varepsilon_r = 5$ and conductivity at $\sigma = 0.04$ S/m. At the height of 2 m on the outside of the top wall there was a cuboid of dielectric parameters: $\varepsilon_r = 2.2$, $\mu_r = 1$, on which a transmitter was placed, emitting a sinusoidal signal of a frequency $f = 2.4$ GHz and amplitude of 1.

Results of the analysis

The assessment of the distribution of the EM field was obtained by using the FDTD method. A comparison of the distribution of the EM field in a fixed state and for a given time step was made.

In Fig. 1.5 the distribution of the EM field was presented inside the analyzed construct made only of concrete. The transfer of the wave through the dielectric (concrete) causes a decrease in the EM field's value. Part of the wave becomes damped by passing through a different medium and reflected multiple times inside the wall, and part of it becomes reflected on the air-dielectric boundary. When comparing the distribution of the EM field in the three analyzed cases, it is visible that the wave spreads more evenly in constructs with no reinforcement both in front of and behind the wall (Figs. 1.5–1.7). In the models with steel rods there are unevenly spreading, numerous shadow zones in the immediate proximity to the wall. Also, reflections of the wave from the rods cause multiple interferences with visible deviations from the even distribution of signal. The amassing of interference within the room (taking into account reflections from all the walls) generally decreases the value of the compound number E_z and the average distribution of the field, which has similar values to the non-reinforced scenario only at a distance of 4 m from the signal source.

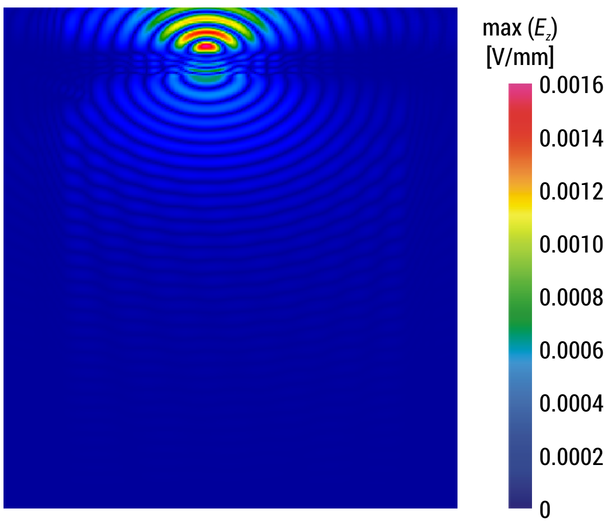

FIGURE 1.5. Reinforcement in the post, top and left wall with absorption conditions (M1)

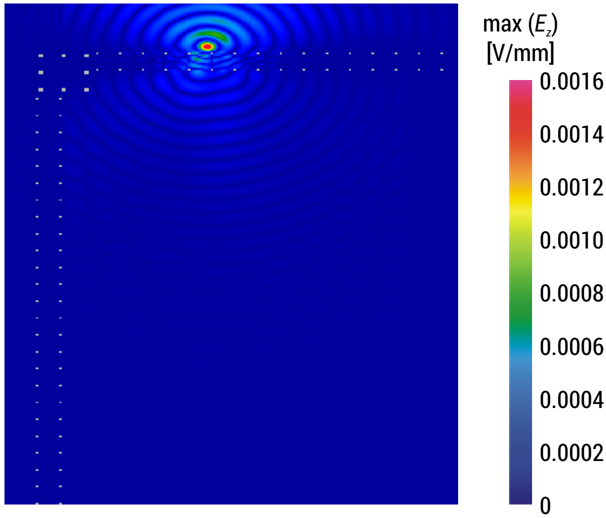

FIGURE 1.6. Distribution of EM field inside a room with reinforcement *Φ* = 8 mm (M2)

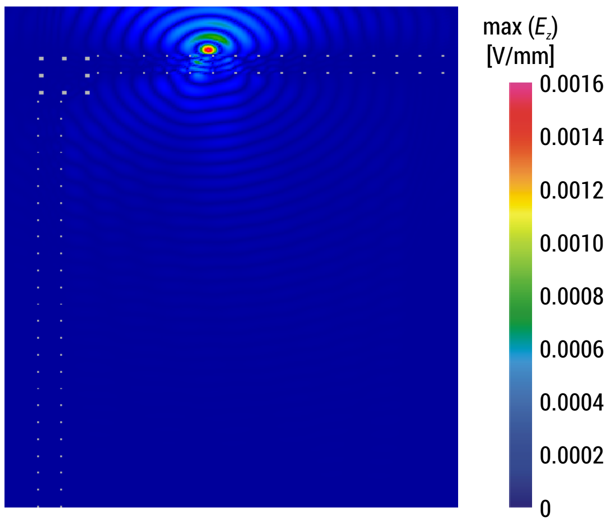

FIGURE 1.7. Distribution of EM field inside a room with reinforcement *Φ* = 12 mm (M3)

The phenomenon of reflection from the walls causes temporary increases in the field's value inside the room. The concrete post construction introduces additional reflections, and the reinforcement within the post participates in the creation of complex processes: reflections on the air-post boundary and the reinforcement-concrete boundary, where multiple reflections take place. The mentioned phenomenon causes an increase in the signal strength, as well as temporary fading in the area close to the reinforced construction (up to 1 m). In the construction with iron rods of 12 mm diameter (M3) the value of the EM field inside the room is comparable with the Φ = 8 mm model (M2). The increase in reinforcement diameter causes only local decreasing of the compound E_z value in areas of the rods and a larger area of the shadow zone (Fig. 1.7). Reinforcement causes a non-uniform distribution of field value and decreasing the compound E_z value by 10–20% on average, in comparison with the model with no reinforcement (Figs. 1.5–1.7).

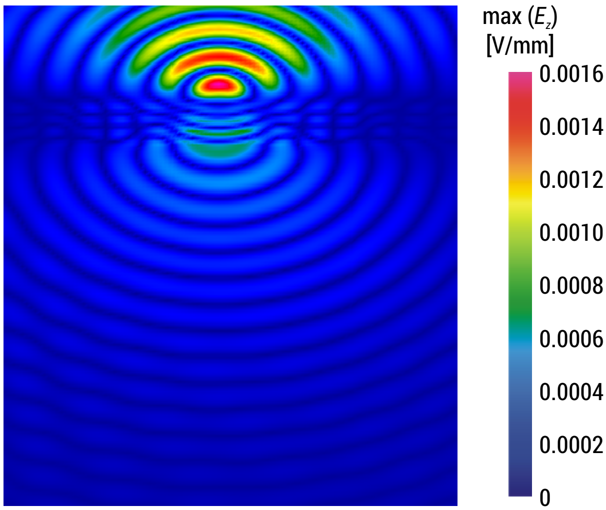

FIGURE 1.8. Proximity zone containing a point source of the field (model composed of only concrete – M1)

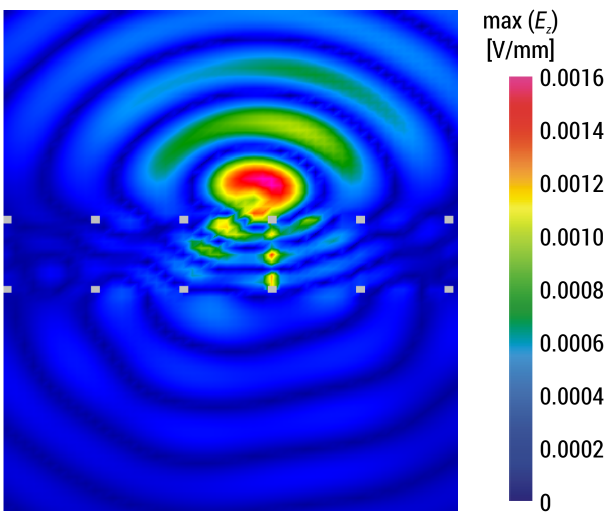

FIGURE 1.9. Proximity zone containing a point source of the field. Model composed of concrete with reinforcements: Φ = 8 mm (M2)

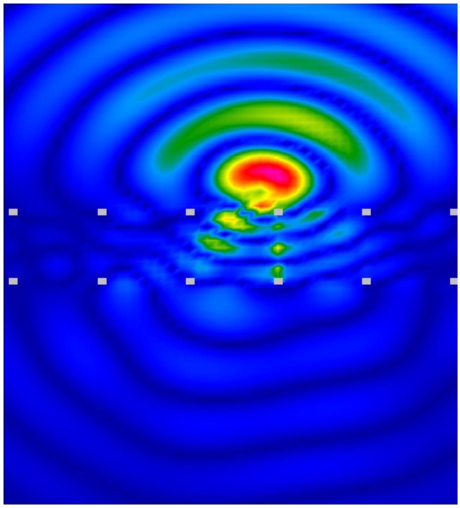

FIGURE 1.10. Proximity zone containing a point source of the field. Model composed of concrete with reinforcements: Φ = 12 mm (M3)

The increase of areas in the proximity to the point source of the field is illustrated in Figs. 1.7–1.9. Clearly visible are the refractions of the EM wave at the air-concrete boundary causing decrease in signal strength, decrease in wavelength and a localized change in the direction of wave propagation. Thicker reinforcement would cause larger areas of signal fading, whereas with appropriately chosen rod diameters and their spacing it would be possible to analyze the issues of screening.

Conclusions

In material mediums the speed of the EM wave is always smaller and depends on the material and frequency. Small non-uniformities of the field cause the wave to partially scatter practically in all directions.

There are many problems with generating and radiating higher levels of power. The analysis of large systems requires consideration of the future application of homogenization of structures in terms of material data in order to, for example, reduce calculation costs related to the reduction of the mesh and obtain more accurate results. The results show that mounting transmitters on walls without reinforcement significantly improves field distribution, because there are no negative effects related to the reflection of waves from metal bars and the distribution is even.

Streszczenie: Celem niniejszej pracy jest analiza rozkładu pola elektromagnetycznego o częstotliwości f = 2.4 GHz wewnątrz pomieszczenia mieszkalnego. Analizie poddano wpływ materiału budowlanego i średnicy zbrojenia na rozkład pola elektromagnetycznego. Do analizy wykorzystano metodę różnic skończonych w dziedzinie czasu (FDTD). Wyniki dowodzą, że montaż nadajników na ścianach bez zbrojenia powoduje równomierne rozłożenie pola elektromagnetycznego. Średnica prętów wpływa jedynie na rozkład pola i jego wartość tylko w odległości do 4 m. Szczegółowa analiza wpływu rodzaju konstrukcji budynku pozwoli rozwiązać problem zanikania. (Wpływ zbrojenia na rozkład natężenia pola elektrycznego).

Słowa kluczowe: bezprzewodowa komunikacja (Wi-Fi), propagacja fali elektromagnetycznej, materiały budowlane, FDTD.

Author: dr inż. Agnieszka Choroszucho, Bialystok University of Technology, Faculty of Electrical Engineering, Wiejska 45D, 15-351 Bialystok, E-mail: a.choroszucho@pb.edu.pl, ORCID: 0000-0001-7884-9264

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Chapter 2
The use of the Arduino and sensors to monitor environmental parameters

Alan Kondrusik, Agnieszka Choroszucho
Bialystok University of Technology, Faculty of Electrical Engineering

Abstract: The article presents the analysis and the possibility of a wide use of the Arduino platform to monitor important environmental parameters with the help of low-cost sensors. Some sensors included in the conceptual design were tested for analysis. A statistical approach was applied in stable and dynamically changing environmental conditions using a computer program and the Arduino platform. The results obtained below make it possible to see the potential for using the project and confirm the usefulness, efficiency and repeatability of the data recorded by the sensors.

Keywords: air quality, sensors, the Arduino, microcontrollers

Introduction

In the modern world, we are dealing with enormous technological progress that contributes to the development of various types of industry. Thanks to this, humanity lives better, but sometimes forgets the huge impact it has on the surrounding environment and ecology. The industrial revolution is one of the most important factors through which large amounts of carbon dioxide, carbon monoxide, sulfur, nitrogen, dust and other gases began to enter the atmosphere. This aspect made it necessary to monitor environmental parameters in practically every possible industry for the sake of people's health and the environment. For this purpose, various companies use specialized programs, embedded systems and sensors that record and transmit data on relevant environmental parameters in real time. An important aspect is the price of such devices, especially sensors, which sometimes reach large amounts. It is required that such devices be as cheap and efficient as possible. Having an inexpensive embedded Arduino system and sensors for detecting e.g. temperature and various gases, this system can be defined as an economical solution to the problem.

There is a large number of low-cost electronic devices on the market, including sensors and embedded systems. With the right equipment and knowledge, one can monitor environmental parameters at a low cost, while achieving high performance of the measuring device. This solution is possible.

This article offers the authors' conceptual design and the results of the analysis, as well as the possibility of a wide application of the Arduino platform and sensors for monitoring environmental parameters.

Arduino – open source hardware/software

Arduino is an open source software / hardware used comprehensively to create independent interactive projects by professionals and hobbyists. Arduino manufactures different types of equipment for different purposes, making equipment use global (Fig. 2.1) [1]. The physical part of the hardware is a PCB of various sizes and functionalities depending on the type of embedded system. It usually contains a certain number of I/O pins, analog pins, power pins, I^2C and SPI pins, crystal oscillators, USB connectors, DC sockets, a RESET button and other components. Device programming is most often done via the Arduino IDE. This cross-platform application allows the use of such languages as Java, C, C ++ and Python, and is compatible with all Windows, Linux, MacOS systems.

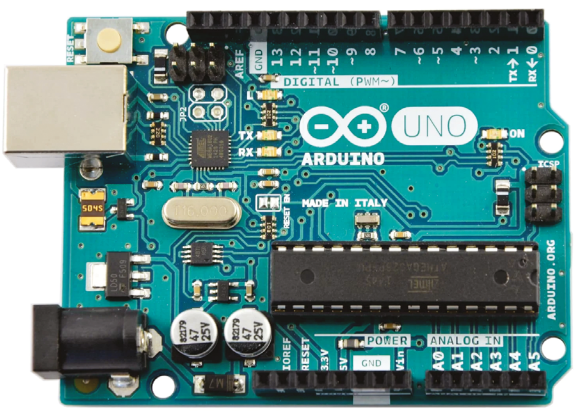

FIGURE 2.1. An example of the original Arduino UNO R3 board

Arduino programming has become greatly functional thanks to the possibility of extending libraries allowing for more efficient work with hardware and data manipulation. One of the main and important functionalities of the microcontroller is reading the signal output data from various types of sensors, e.g. temperature and humidity sensors, pressure sensors, sensors of various gases concentration in the air. For this, specific sensor libraries are used, which contain the control instruction and the type of signal being sent. The microcontroller reads the data sent from the sensor using an analog or digital method. The analog method consists in observing the change in the generated voltage produced by an analog sensor and processing it in such a way that it reflects the real data. In contrast, the digital method reads discrete values, i.e. 0 or 1, which are binary / digital signals from a digital sensor. Thanks to these methods, the Arduino microcontroller can handle various types of digital and analog sensors in a practical application.

Description of the structure and elements of the measurement system

To check and evaluate the usefulness and efficiency of cheap sensors monitoring environmental parameters, a temporary measurement system was made, consisting of thermal and gas sensors based on the Arduino Nano V3 microcontroller (Fig. 2.2) [2].

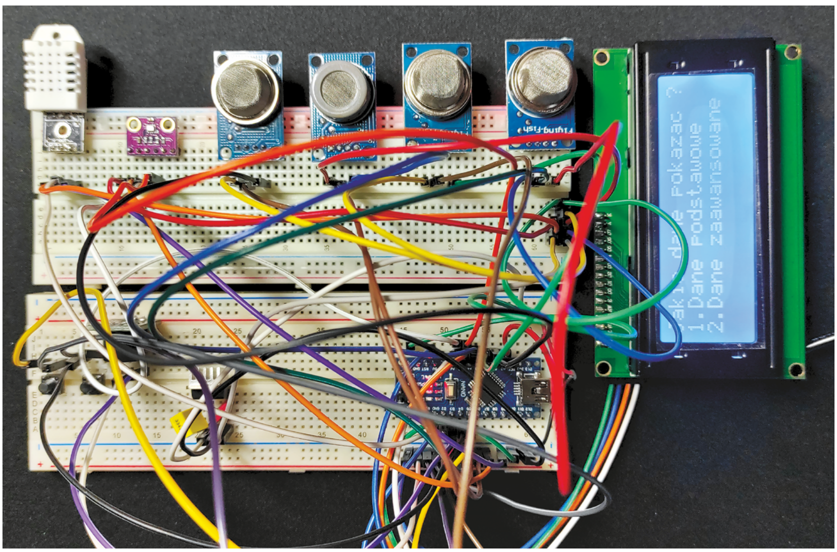

FIGURE 2.2. Prototype measurement system based on the Arduino Nano V3 microcontroller

The construction of the station was designed in such a way as to ensure a constant and stable propagation of current and voltage to the elements of the electric circuit, thanks to which the noise and errors during the operation of the equipment can be reduced. Contact plates, which are a passive element, became the temporary base on which the electronic components were placed. Finally, the project was made on a designed PCB with dimensions of 12×8 cm in the popular engineering program Eagle by Autodesk (Fig. 2.3).

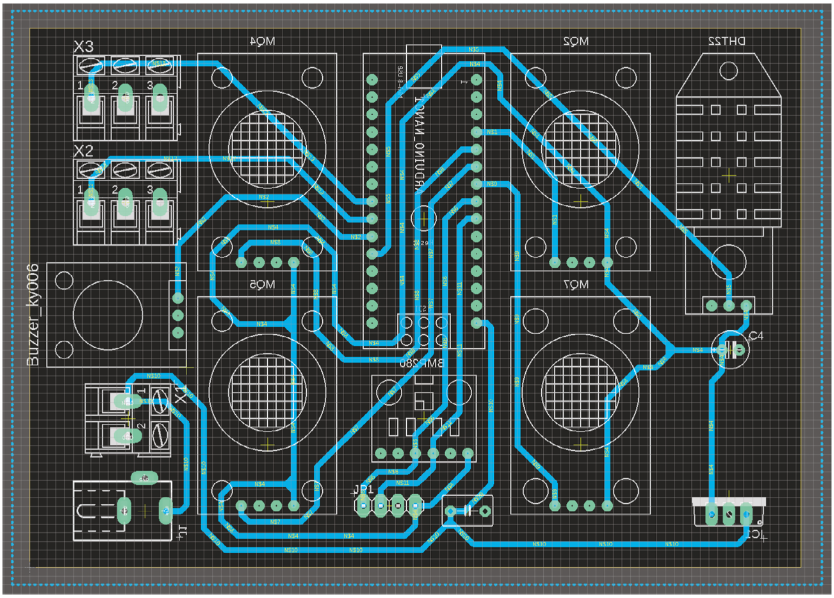

FIGURE 2.3. **Visualization of the PCB with connections between system components**

Male-male and female-male cables were used to connect each electronic element into a whole. In the design, the popular LM7805 linear voltage stabilizer was used for the stable propagation of the current and voltage to each sensor [3]. The power supply system is a simple 9 V/1 A DC power supply, which supplies voltage in parallel to the microcontroller and the voltage regulator. The control system of the measurement system consists of the used Arduino Nano V3 microcontroller powered by 9 V voltage, which provides data reading and two Tact Switch buttons, which are programmed to switch between displaying specific data of subsequent sensors on the display. For convenient analysis of the results, the universal HD44780 LCD 4x20 display was used, which presents readable measurement data, e.g. in a numerical manner, supplied with 5 V [4]. The measuring system consists of such sensors as MQ2, MQ4, MQ5, MQ7, DHT22 and BMP280. Optionally, a small buzzer with a generator was added to the design to signal the achievement of a certain level of gas concentration. Each element (Fig. 2.4) used to create the measuring station was checked before starting the measurements. Additionally, capacitors with a capacity of 330 nF and 100 nF were used, which help to stabilize the voltage in the LM7805 stabilizer.

The DHT22 temperature and humidity sensor was selected for this project as it is one of the most widely used low-cost sensors in engineering projects [5]. The operating temperature of this sensor is from – 40°C to 80°C with an accuracy of 0.1°C, while the humidity measurement range is 0–100% with a resolution of 0.1% and an accuracy of 2–5% RH. The MQ2, MQ4, MQ5 and MQ7 sensors are a class of cheap gas sensors with high measurement efficiency [6–9]. They are similar to each other with regard to the range of gas detection, which is between 10–10,000 ppm units. Their operating temperature is – 20°C to 50°C. The BMP280 sensor is a popular atmospheric pressure sensor that allows measurements in the range from 300 hPa to 1100 hPa [10]. Its operating temperature range is from 40°C to 85°C and the measurement accuracy is 1 hPa. The nominal supply voltage of all sensors is 5 V. The sensor communication system between the Arduino is based on one analog and digital signal bus, while the HD44780 display and the BMP280 sensor are based on two SCL and SDA buses, clock signal and data line in turn. The MQ2, MQ4, MQ5 and MQ7 sensors were connected to the Arduino in turn to the analog pins A0, A1, A2, A3. The DHT22 sensor was connected to the digital pin D2, while the BMP280 sensor and the HD44780 display were connected to two I^2C pins, i.e. SCL and SDA, which correspond to Arduino pins A5 and A4, respectively. The buzzer is connected to the digital pin D3, while the Tact Switch buttons are connected to the digital pins D4 and D5.

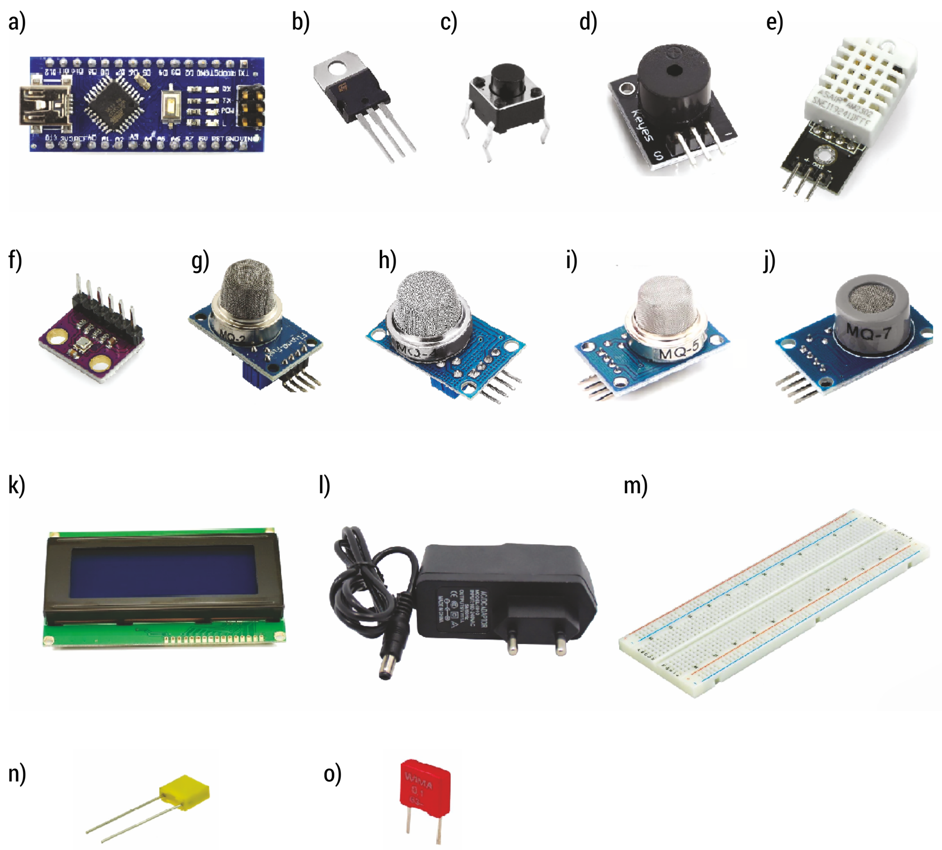

FIGURE 2.4. Arduino Nano V3 (a), LM7805 (b), Tact Switch (c), Buzzer (d), DHT22 sensor (e), BMP280 sensor (f), MQ2 sensor (g), MQ4 sensor (h), MQ5 sensor (i), MQ7 sensor (j), HD44780 display (k), power supply (l), contact plate (m), capacitor 330 nF (n), capacitor 100 nF (o)

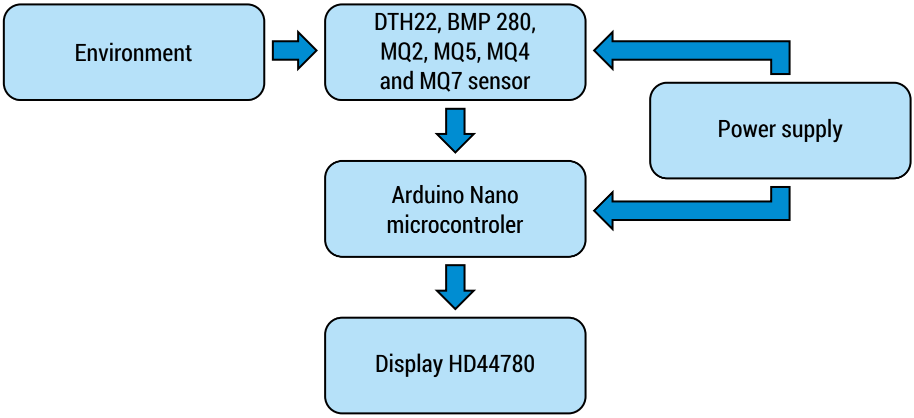

FIGURE 2.5. **Block diagram of the measurement system**

To fully understand the idea of operation and the way of communication of each electronic element (Fig. 2.5), a simple block diagram was made, which includes connections between the most important segments of the mechanism.

Analysis of the results

The MQ7 sensor and the DHT22 sensor were selected from among several sensors to check the usability and functionality of the design idea. The program that supports the entire system was written in the Arduino IDE programming environment in C [11], where the functions were compliant with the Arduino program guidelines. The idea of the code (Fig. 2.6) is presented in the form of a simple diagram that explains how the program performs its task and controls various activities.

The main task of the MQ7 sensor is to record the concentration of carbon monoxide in the surrounding environment. Its presence pollutes the air and causes damage to human health, even in small amounts [12]. This compound is odorless, hence such a sensor should be used that is capable of detecting this gas. As part of the experiment to assess the usefulness, precision and repeatability of measurements, the MQ7 sensor was subjected to an attempt to read the content of carbon monoxide CO in the air in an office room, but with a variable and constant value of this compound at room temperature. The first day shows CO concentration in a ventilated environment, while the next day shows CO concentration in a slightly polluted but constant environment. The graph (Fig. 2.7) clearly shows that the repeatability precision of this sensor is at a very high level. It has been found that a cheap environmental sensor under stable conditions can withstand and display data that is identical throughout the experiment.

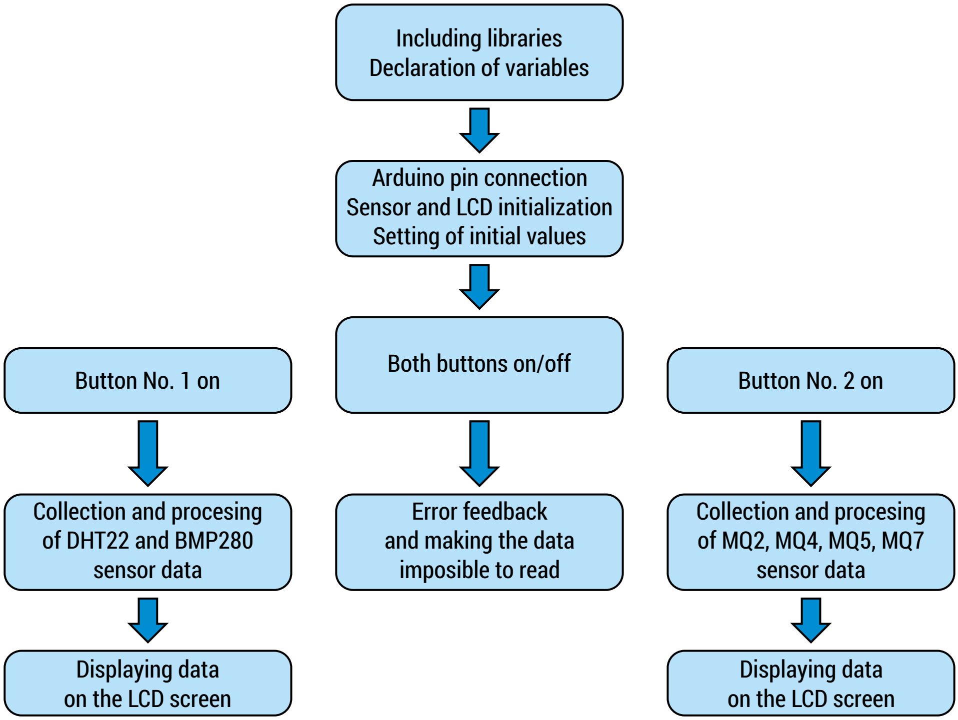

FIGURE 2.6. **Block diagram of the program operation**

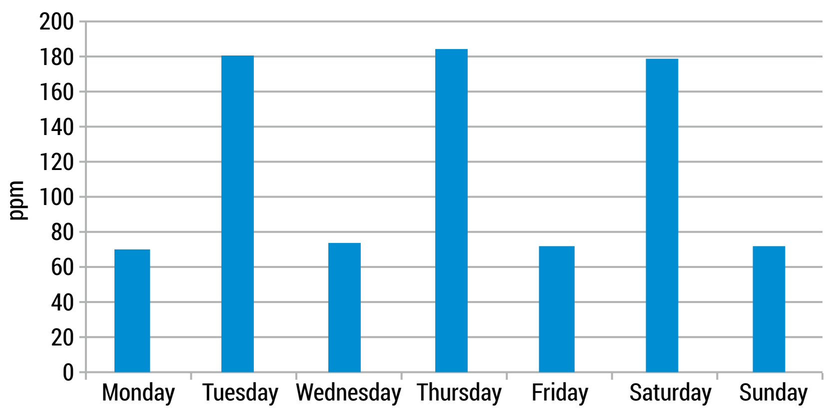

FIGURE 2.7. **Daily diagram of average concentration of CO carbon monoxide in stable environmental conditions read by the MQ7 sensor within 7 days**

The graph below (Fig. 2.8) shows changes in the concentration of CO in the air in an environment where the concentration of this compound changes dynamically. From the moment the carbon monoxide CO is injected close to the sensor head, an increase in the content of a harmful chemical compound in its surroundings was immediately read, and thus the program triggered the alarming loudspeaker.

At the time when the content of CO carbon monoxide in the environment was generally determined, the information obtained from the sensor was not sudden and it was necessary to wait several seconds for the sensor to notice any increase in the concentration of the harmful agent, which was shown by slight fluctuations in the graph. It has been noticed that the sensor reacts very quickly to changes in environmental parameters. Its repeatability in this case is also good. The stability of the sensor's operation was observed after many fatigue tests despite drastically changing environmental parameters, which proves its usefulness and high efficiency. In both environmental cases, the results of the other gas sensors, i.e. MQ2, MQ4 and MQ5, were identical.

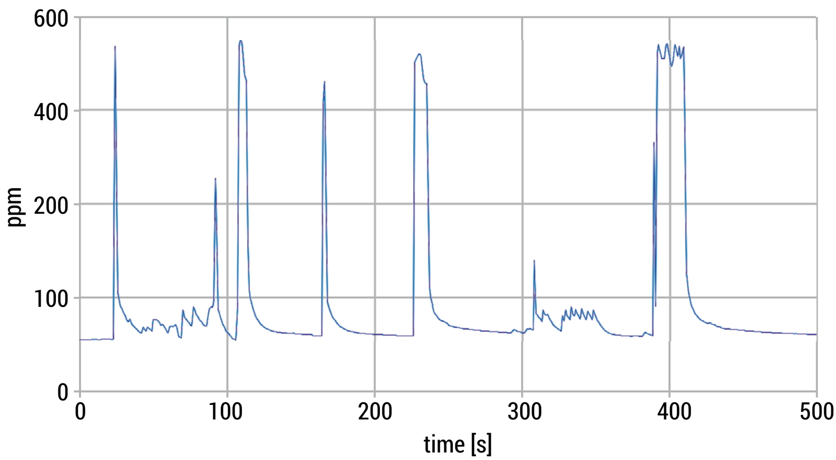

FIGURE 2.8. **Graph of CO concentration under dynamic environmental conditions read by the MQ7 sensor during 5 minutes**

The DHT22 sensor checks the temperature and humidity of the environment in which it is located. These are parameters that should be read virtually anywhere, especially the temperature value, e.g. in a building / room, laboratory, production hall, etc. In order to estimate the precision and accuracy of the measurements of the DHT22 sensor, an experiment was performed consisting in placing the sensor at room temperature and outside temperature for 7 days without interruption. The temperature data from the DHT22 sensor was compared with a professional Ferroli home automation sensor (Fig. 2.9) and a normal sensor intended for outdoor use (Fig. 2.10) [13]. It has been observed that the values indicated by the cheap temperature sensor are identical to the sensors from the higher price range. Despite the low temperature environment, the sensor was as good as the sensor intended for this environment.

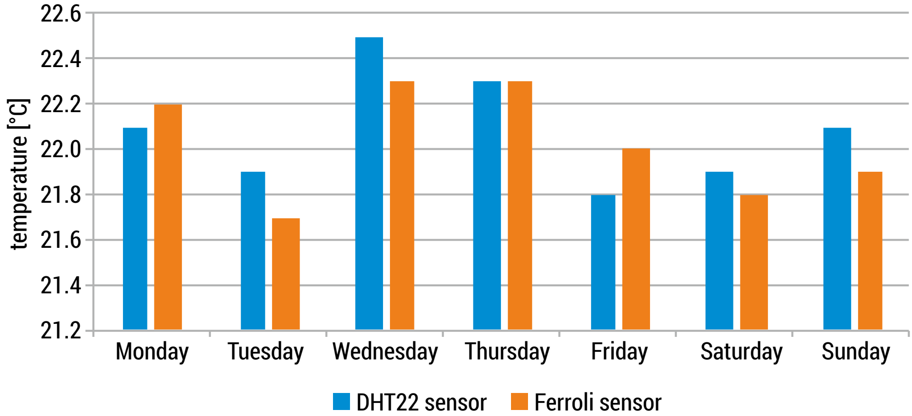

FIGURE 2.9. A graph comparing the average daily room temperature of the DHT22 sensor and the Ferroli sensor over 7 days

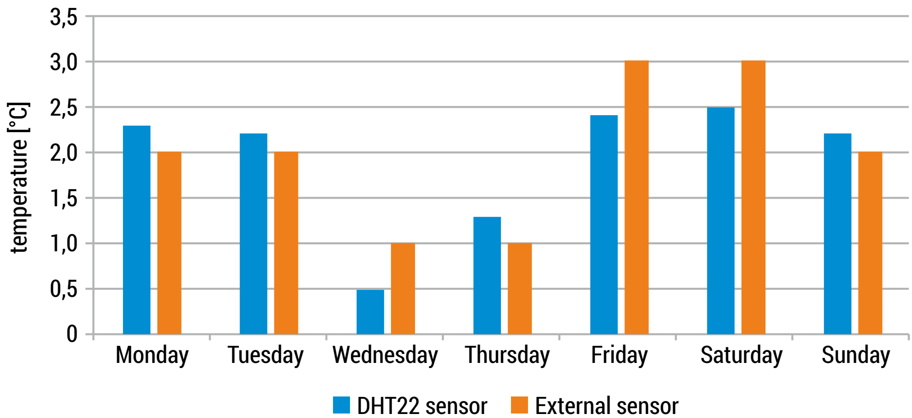

FIGURE 2.10. A graph comparing the average daily outside temperature of the DHT22 sensor and the Ferroli sensor over 7 days

Summary and Conclusions

The article presents the results of measuring the effectiveness of the conceptual design of a handheld or stationary measurement system for recording important environmental parameters using an Arduino microcontroller and sensors. The purpose of the analysis was proving a practical and cheap solution of obtaining data on environmental conditions, practically anywhere.

The obtained results show the real precision, reliability and significant measurement performance that occurs in inexpensive electronic sensors available on the market, in a stable and dynamically changing environment. Under the assumed project conditions, the values shown in the charts confirm the fact that it is possible to create a cheap, precise and universal device for measuring environmental parameters. The speed of the program and sensors that read analog signals from the surrounding environment show the great potential of the above design in practical application.

In order to improve the mobility of the device, it is possible to connect the system to a compact battery. Thanks to this solution, the equipment can be used for a long time without access to energy from the grid. Thanks to the miniaturization of the design with the simultaneous use of many sensors, the device opens up many possibilities. It can be used in drones checking the composition of smoke coming from chimneys, e.g. home, industrial factories. Sensors can be successfully used to regulate air parameters in a home heat recovery system. The project enables the use of wireless communication, e.g. Wi-Fi, thanks to which it will be possible to connect many such devices and multiply the range of applicability of the entire system on a larger scale. With proper calibration, this system is able to detect very small amounts of harmful chemical compounds, e.g. in a laboratory.

Research work on the project will be continued taking into account the location, durability, precision and miniaturization of the entire project.

Streszczenie: Artykuł przedstawia analizę i możliwość szerokiego wykorzystania platformy Arduino do monitoringu ważnych parametrów środowiska przy pomocy niskobudżetowych czujników. W celu analizy przetestowano niektóre czujniki wchodzące w skład koncepcyjnego projektu. Zastosowano podejście statystyczne w stabilnych i dynamicznie zmieniających się warunkach otoczenia przy pomocy programu komputerowego oraz platformy Arduino. Uzyskane niżej wyniki pozwalają dostrzec potencjał wykorzystania projektu oraz stwierdzają użyteczność, wydajność oraz powtarzalność danych zarejestrowanych przez czujniki. (Wykorzystanie Arduino i czujników do monitorowania parametrów środowiskowych)

Słowa kluczowe: jakość powietrza, czujniki, Arduino, mikrokontrolery

Authors: dr inż. Agnieszka Choroszucho, E-mail: a.choroszucho@pb.edu.pl; Alan Kondrusik, E-mail: kondrusik.alan@gmail.com; Bialystok University of Technology, Faculty of Electrical Engineering, ul. Wiejska 45D, 15-351 Bialystok, ORCID: 2. 0000-0001-7884-9264

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Chapter 3
Analysis of the efficiency of a solar station for charging personal electric vehicles

Agnieszka Choroszucho, Damian Orzechowski, Mateusz Sumorek, Jakub Żukowski
Bialystok University of Technology, Faculty of Electrical Engineering

Abstract: Popularizing ecological life, reducing human impact on the environment, and ultimately striving for zero emissivity is significantly visible in the media. In recent years, the significant development of the automotive industry in the field of electric cars and programs popularizing renewable energy sources, have contributed to the growing interest of the public in personal electric vehicles, e.g. scooters, bicycles, skateboards. The exploitation of such a vehicle requires charging. The research results presented in the article will allow estimating the practical potential of solar stations for charging personal electric vehicles in urban space. Analysis of the efficiency of a solar station for charging personal electric vehicles.

Keywords: renewable energy sources, energy efficiency, electric vehicles, charging.

Introduction

Nowadays, there is a significant increase in the interest in electric vehicles. Last years resulted in popularization of cars, bicycles, scooters, skateboards and other vehicle variations. In urban space we can observe more often people using such solutions, and electronic scooters offered by rental companies have already become a common feature of city landscapes. Each year more and more emphasis is placed on reducing pollution and striving for zero emissions, not only in terms of transport but also industry and energy. The European Union aims to exclude combustion cars from production by 2035 [1].

Combining the above mentioned facts with the better availability of these technologies and changes in the habits of society in last years lead to a new market trend related to the provision of electricity for personal electric vehicle. People using such a vehicles for transport e.g. to work, school, university, must store these vehicles somewhere and sometimes charge their battery packs. It is highly complicated in public places or office spaces, where several such vehicles significantly take up free space. Therefore, a concept was created based on bicycle shelters combined with electrical infrastructure powered by photovoltaic panels in order to charge parked vehicles.

This article presents the results of the performed analysis. It shows the efficiency results of such a charging station, taking into account practical factors. Finally, it aims to develop conclusions to improve the solution.

Environmental conditions

The basic aspect that must be taken into account during the creation of any project that uses a photovoltaic system is its location. It is mainly the geographical location that is the most important as in some areas such an installation may not be economically and practically justified. If the initial classification is successful, it is important to make an on-site visit to verify the concept of such an installation e.g. whether it will not be overshadowed by another building. The success of this phase should guide to the design phase during which the physical position of the panels will be specified [2].

The described project assumes a structure in the form of a canopy where the roof would be replaced with photovoltaic panels. Its location was established on the northern side of the campus of Bialystok University of Technology, near the building of the Faculty of Electrical Engineering (Fig. 3.1). Such a location – due to the openness of the space to the east, south-west and south – allows to minimize the risk of shading the area in which the station is located. By these means it is possible to maximize the time of using solar energy while staying close to the building.

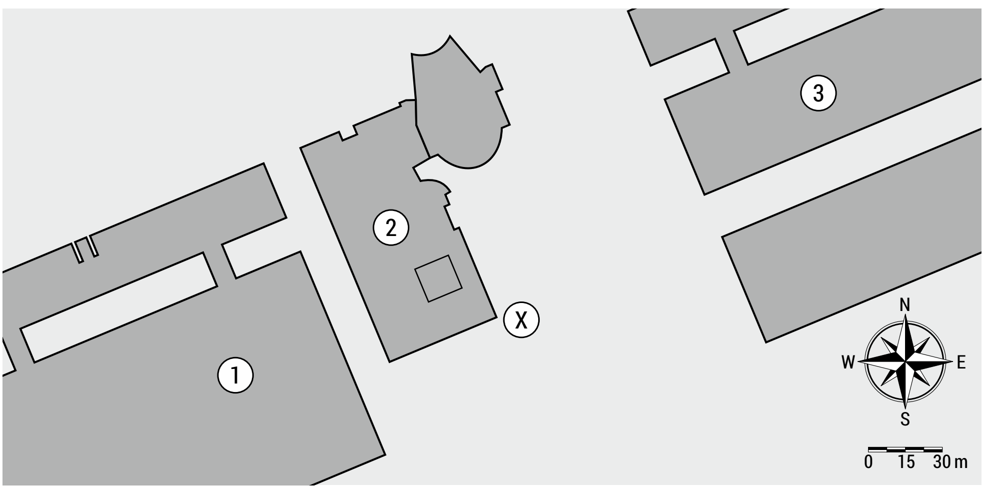

FIGURE 3.1. Fragment of the campus map; 1 – Faculty of Mechanical Engineering, 2 – Faculty of Electrical Engineering, 3 – Faculty of Civil Engineering and Environmental Sciences, X – proposed location of charging station

In order to reduce the area of environmental data analysis, the period was taken into account in which there is an increased number in road users using personal electric vehicles. This period was defined between April and October.

TABLE 3.1. Long-term average (1991–2014) of solar radiation power in Bialystok [3]

Month	Average power [W/m^2]
April	170
May	190
June	240
July	220
August	200
September	120
October	80

The data of the Institute of Meteorology and Water Management [3] show the average long-term solar radiation power in the given months in Poland. Table 3.1 shows the read (approximated) data for the Bialystok region. In the analysis, for the sake of simplicity, long-term monthly average data were adopted. This allows ignoring the position of the sun during the day or changing weather conditions, while maintaining an accepted accuracy in long-term calculations.

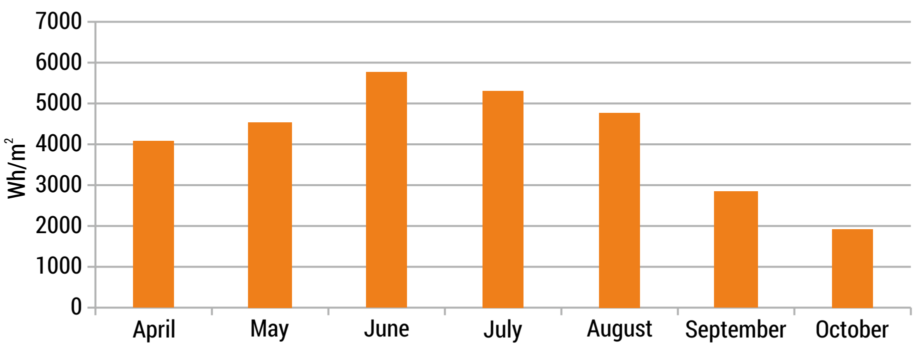

FIGURE 3.2. Diagram of energy supplied daily (average) in a given period to the station in a given month per m^2 of surface

Mean values were converted into watt hours according to the formula:

$$P\ [W/m^2] \cdot t\ [h] = Wh/m^2. \tag{3.1}$$

This procedure allowed to adjust the value of energy supplied to the station per m^2 of the photovoltaic panel area (Fig. 3.2).

Construction

The construction of the station was designed in such a way to provide not only support for the photovoltaic panels, but also to act as a parking shelter to store personal electric vehicles. This way it is possible to optimize the use of the available space. It is desirable in the construction of modern urban infrastructure and private properties, where every square meter counts.

The frame of the shelter consists of closed steel profiles of various sections. The four main supports are made of a profile with dimensions of 60 × 60 × 3 mm and respectively a height of 2200 and 3180 mm. The construction underneath photovoltaic panels is made of profiles with dimensions of 30 x 30 x 2 mm. The entire station measures 4 x 1,4 x 3.18m. The lean angle of the photovoltaic panels (Fig. 3.3) called α, was selected according to the geographical position of Poland, based on the average values of the solar inclination during the year. The α angle measures 35°, although a wide range is allowed, from 20° in the south of Poland to 40° in the north [4, 5].

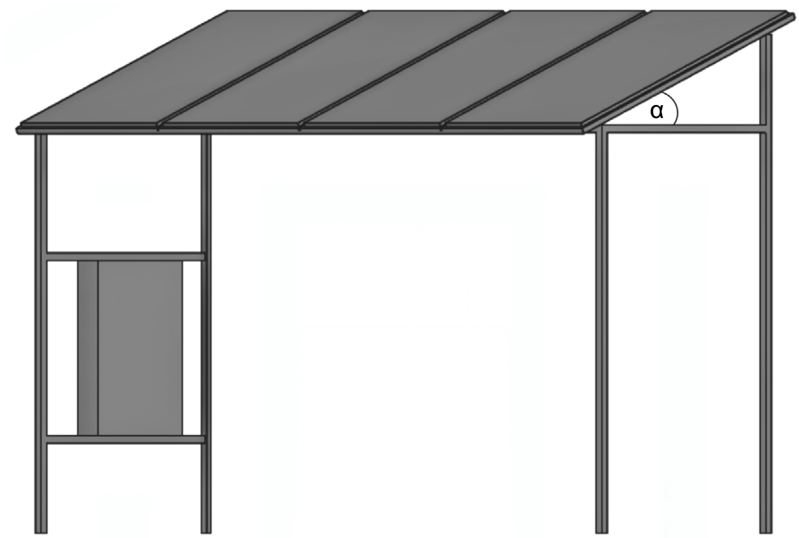

FIGURE. 3.3. Visualization of the station structure from the CAD program

All electronic and power electronic components (Fig. 3.4) were placed in a hermetic box dedicated for the assembly of electrical equipment. The box is locked with a key, which prevents access by unauthorized persons. On the front there are 230 V mains sockets for connecting vehicles.

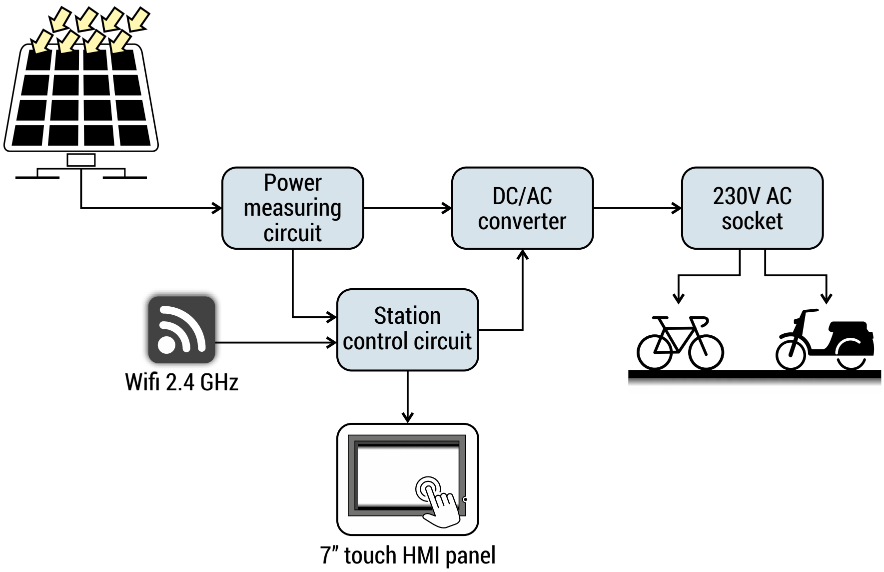

FIGURE. 3.4. Block diagram of the solar station

The control system of the station is based on the ESP8266 microcontroller with 2.4 GHz Wi-Fi wireless connectivity and will ultimately work in the network as an IoT device [6]. Network functions allow for remote control of electrical parameters including power consumed by vehicles and the amount of generated energy for a given period (e.g. day or month). The station will be operated by a 7-inch touch display from Nextion, which functions as an HMI panel.

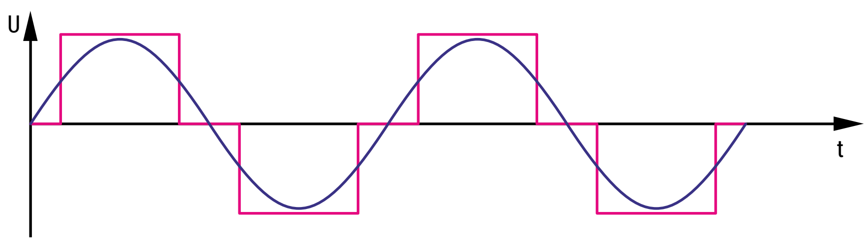

FIGURE. 3.5. Waveforms, blue line – sine wave, pink line – modified sine wave

The used DC/AC converter has a continuous power of 1000 W and a momentary power of 2000 W. The inverter generates an output voltage in the form of the modified sine wave (Fig. 3.5). This choice was motivated by the fact that the energy receiver is also a pulse converter (AC/DC), which acts as a vehicle charger. Therefore, it is not necessary to use an inverter at the station providing a sine wave at its output. Also this would be associated with higher costs. The declared efficiency of the applied converter is 85%. This value was taken into account in further calculations of the station's efficiency.

Results

Four photovoltaic panels with a rated power of 280 Wp each generate electricity. The entire station has a rated power of 1.12 kWp. According to the manufacturer's data, one photovoltaic panel consists of 60 cells with dimensions of 156 × 156 mm. It follows that the effective area of all four panels is:

$$S = 4 \cdot 60 \cdot 0{,}156\ \mathrm{m} \cdot 0{,}156\ \mathrm{m} \approx 5{,}84\ \mathrm{m}^2. \tag{3.2}$$

The efficiency of photovoltaic panels declared by the manufacturer is 17.21%.

TABLE 3.2. Values of the average power falling on the surface of the panels, power at the output of the panels and monthly energy at the output of the station, taking into account the efficiency of the converter

Month	Delivered power [W/5,84m^2]	Output power [W]	Gross energy [kWh]
April	992.8	145.23	104.57
May	1109.6	162.32	116.87
June	1401.6	205.03	147.62
July	1284.8	187.95	135.32
August	1168.0	170.86	123.02
September	700.8	102.52	73.81
October	467.2	68.34	49.21

Based on all the data presented so far, it is possible to estimate the amount of energy produced by the station. The results of the calculations are shown in Fig. 3.6.

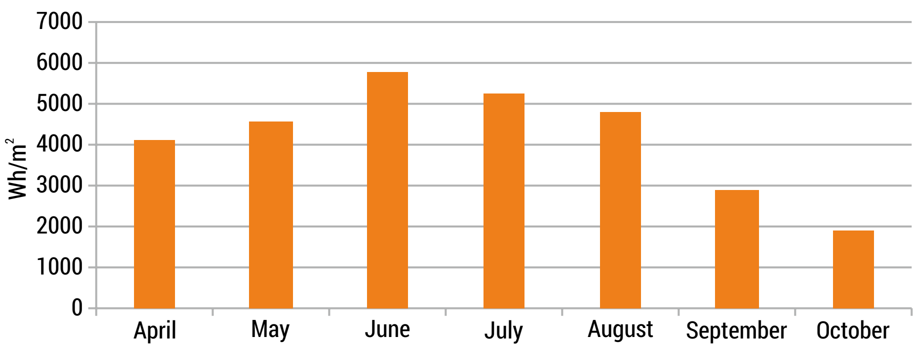

FIGURE 3.6. Graph of the energy produced (gross) by the station in the given months based on the data in Table 2

It is assumed that the station can produce about 0.75 MWh of energy during the entire season.

Results analysis

In order to draw the practical use of the obtained results, an analysis of the personal electric vehicles available on the market was carried out. On the basis of the data declared by selected manufacturers and own experience, an approximate summary of energy consumption expressed in Wh per kilometer of the vehicle has been developed.

The presented data (Table 3.3) are mean values expected under optimal conditions. They do not take into account weather, terrain conditions, load and other factors that may significantly affect the range of the vehicle. On their basis, it can be seen that average energy use for different personal electric vehicles is similar. The mentioned fast electric bikes and motorcycles are characterized higher energy demands. Vehicle range can be estimated based on the average battery capacity and energy obtained from the sun. For analytical purposes, it was assumed that the efficiency of the charger is 80%.

TABLE 3.3. Electricity consumption per distance travelled by selected groups of vehicles.

Type of electric vehicle	Energy usage [Wh/km]	Average energy usage [Wh/km]
Bike	10–20	15
Scooter	9–20	14.5
Skateboard	8–20	14
Sports bike or light electric motorcycle [7]*	20–50	35

* – Vehicles with curb weight above 50 kg

TABLE 3.4. Estimated vehicle range for a given battery capacity

Type of electric vehicle	Battery capacity [Wh]	Estimated vehicle range [km]
Bike	816	54.4
Scooter	460	31.7
Skateboard	192	13.7
Sports bike or light electric motorcycle **	4000	114.3

** In the case of this type of vehicles, the capacity discrepancy is large, from 1 kWh to even 8 kWh

On the basis of the collected data, it is possible to estimate the efficiency of the station in terms of the number of fully charged electric vehicles per month, taking into account the influence of the charger efficiency.

TABLE 3.5. Number of fully charged vehicles from the station per month

Month	Bike	Scooter	Skateboard	Sports bike or light electric motorcycle
April	103	182	436	21
May	115	203	487	23
June	145	257	615	30

Month	Bike	Scooter	Skateboard	Sports bike or light electric motorcycle
July	133	235	564	27
August	121	214	513	25
September	72	128	308	15
October	48	86	205	10

The table above shows the number of complete charging cycles for a given vehicle. The analysis assumed that only one type of vehicle would be loaded at the station, for example only bicycles or only scooters. Based on the data, it is possible to calculate the possible distance to be travelled by the vehicle, provided that it is charged only with energy from the station.

TABLE 3.6. Estimated distance travelled by a vehicle that uses energy only from the station (km)

Month	Bike	Scooter	Skateboard	Sports bike or light electric motorcycle
April	5577	5765	5969	2390
May	6233	6443	6671	2672
June	7873	8139	8427	3375
July	7217	7460	7725	3093
August	6561	6782	7022	2812
September	3937	4069	4213	1687
October	2624	2713	2809	1125

The above analysis shows that the most efficient means of transport in terms of energy consumption is the electric skateboard. Unfortunately, this vehicle has the shortest range. A light city bike or an electric scooter can cover a similar distance in a given period. At the end of the list are sports bikes and light electric bikes. They have the greatest range and maximum speed, but also the highest energy consumption.

Summary and conclusions

The article presents the results of the analysis of the efficiency of the solar station project for charging personal electric vehicles. The purpose of this analysis was to determine the practical utility of the presented solution, to identify its disadvantages and to select potential solutions in order to improve functionality.

The obtained results represent the actual values of energy that can be obtained from the solar station. With the assumed parameters, these values can be used in a practical way for charging. This would enable users to improve the comfort of using personal electric vehicles.

This analysis looks at efficiency in the general energy bill. The presented project assumes the construction as an independent unit. Not loading the station results in not using energy. Attempts to use the station outside the sunny hours, during unfavorable weather conditions or its excessive load will result in poor results.

In order to improve the real practical aspects, it is possible to connect the station to the power grid. Thanks to this solution, the continuity of the station's operation will be ensured, regardless of sunny or weather conditions. Such a solution, however, is associated with the deterioration of the economic aspects by increasing technical requirements [8] and increasing legal requirements in order to make it available for public use.

An alternative solution is to expand the station with energy storage. This approach allows for an autonomous form of the station. Moreover, with the correct estimation of the storage capacity, it is possible to maximize the use of the energy produced at the same time, allowing the station to be used 24 hours a day, regardless of weather conditions and also increasing its load capacity (within the warehouse capacity). However, this solution is associated with an increase in project implementation costs and the need for additional research in order to correctly estimate storage capacity so that its size is economically justified.

The research will be continued as the project develops, taking into account actual use, location and design improvements.

Streszczenie: Popularyzacja ekologicznego życia, redukowanie wpływu człowieka na środowisko, a finalnie dążenie do zero emisyjności znacząco się odznacza w przestrzeni medialnej. W ostatnich latach znaczący rozwój przemysłu motoryzacyjnego w gałęzi aut elektrycznych oraz programy popularyzujące odnawialne źródła energii, przyczyniły się do wzrostu zainteresowania społeczeństwa osobistymi pojazdami elektrycznymi, np. hulajnogami, rowerami, deskorolkami. Eksploatacja takiego pojazdu wiąże się z koniecznością jego ładowania. Przedstawione w artykule wyniki badań pozwolą na oszacowanie praktycznego potencjału solarnych stacji ładowania osobistych pojazdów elektrycznych w przestrzeni miejskiej. Analiza sprawności stacji solarnej do ładowania osobistych pojazdów elektrycznych.

Słowa kluczowe: odnawialne źródła energii, efektywność energetyczna, pojazdy elektryczne, ładowanie.

Authors: dr inż. Agnieszka Choroszucho, E-mail: a.choroszucho@pb.edu.pl; Mateusz Sumorek, E-mail: mateusz.sumorek@gmail.com; Jakub Żukowski, E-mail: jakubzzukowski@gmail.com; Damian Orzechowski, E-mail: damian.orzechowsky@outlook.com; Bialystok University of Technology, Faculty of Electrical Engineering, Wiejska 45D, 15-351 Bialystok, ORCID: 1. 0000-0001-7884-9264

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Chapter 4
Air quality monitoring device to optimize working and learning conditions

Agnieszka Choroszucho, Mateusz Sumorek, Jakub Żukowski
Bialystok University of Technology, Faculty of Electrical Engineering

Abstract: Social awareness of the quality and cleanliness of the air around us is growing every year. Especially during the heating season, the media are discussing these issues. Measures to reduce the emission of its pollutants are undertaken more and more often. Undoubtedly, its condition affects our health and well-being. Running a company, not only industrial one, is associated with process optimization in order to reduce expenses and maximize profits. In the case of mental work, its effectiveness will be largely influenced by well-being, and therefore the quality of air in the workplace. It happens similarly in a place of study, where the results are dictated by the conditions in which one is staying. The design of the air monitoring device presented in the article allows for the analysis of working and learning conditions in order to take actions to improve them. Air quality monitoring device to optimize working and learning conditions.

Keywords: air quality, carbon dioxide, IoT, home automation

Introduction

In recent years, there has been an increase in public awareness of air cleanliness and quality. The media more and more often discuss the issues of smog, exhaust gases, pollution caused by technological processes or the use of harmful materials and substances in various areas of life. The popularization of these issues results in increasing public interest in the impact of the environment in which they work or live on their health. The growing interest in the subject of electromobility, electric and hybrid cars and issues related to renewable energy sources is similar – they all are to reduce environmental pollution.

Nowadays, in every branch of the economy, there is an attempt to optimize processes or activities. The goal is to maximize the effects and profits with minimal effort or at the lowest possible cost. At the beginning of the 20th century, the establishment of the International Labour Organization resulted in the reduction of the working day to 8 hours [1], which was largely due to the dynamic development of industry. The automation of technological processes allowed for the reduction of employees, shortening their working time, while offering similar or better results.

Currently, in developed countries, enterprises often based on intellectual value play a significant role in the economy. The basis for its creation is human intellectual work – not physical. The effectiveness of its results will be influenced by the ability to concentrate, and therefore the environmental conditions of the workplace – including air quality – are of key significance. In many cases, in this area of the economy, working hours have a smaller impact on performance than workspace conditions.

Taking into account all the above-mentioned factors, there is a need for a technical solution enabling air quality testing in a working or residential space so that it could be available to a wide group of recipients, at the same time offering reliable measurement results. In addition, the device would enable integration with existing home automation systems (to control air conditioning, heating, mechanical ventilation). At the same time, it would ensure the scalability of the created system and would allow for the collection and sharing of results in order to conduct research so as to be able to effectively optimize the work.

Defining air quality

Air quality is a slogan that is increasingly appearing in the public awareness. The market offers more and more devices in the form of air purifiers, which are designed to reduce small particles. At this point, there is some doubt as to what, and specifically by what parameters, defines air quality.

The most popular air quality index is AQI (Air Quality Index, Table 4.1) [2]. It is worth noting that the AQI indicator has different varieties depending on the country or region [2, 4, 5, 6]. It determines the effect on health on the basis of concentration values of individual substances [3]. According to the information of the Chief Inspectorate for Environmental Protection (Poland) [4], these factors are:

- solid particles PM 10 and PM 2,5,
- O_3 (ozone),
- NO_2 (nitrogen dioxide).
- SO_2 (sulphur dioxide),
- C_6H_6 (benzene),
- others.

The conditions in which one stays, lives or works affect the well-being of a person. The effectiveness of the tasks performed, especially during mental work in closed rooms, will clearly depend on the conditions prevailing there. Research shows that air temperature, its humidity, pressure and the concentration of carbon dioxide in it influence the well-being of a person [7, 8, 9]. Ultimately, these factors will affect the quality of work.

TABLE 4.1. AQI values and determination of air quality [2]

Daily AQI Color	Levels of Concern	Values of Index
Green	Good	0 to 50
Yellow	Moderate	51 to 100
Orange	Unhealthy for sensitive groups	101 to 150
Red	Unhealthy	151 to 200
Purple	Very Unhealthy	201 to 300
Maroon	Hazardous	301 and higher

Based on the above information, it can be observed that various indicators or factors can define air quality. The aim of the project is to optimize working and learning conditions, hence the measurements are oriented towards closed spaces. Temperature, humidity, pressure and CO_2 concentration were assumed as measured values.

Measurement of non-electrical values

The basis for the effective operation of a measuring device is the appropriate selection of transducers that enable the measurement of selected physical quantities. In the selection it is important to follow the criteria set for the project, such as price, accuracy, size and working conditions.

Currently, there are various systems available on the market to measure the concentration of carbon dioxide. They differ in the method of measurement, price, size or consumed energy.

The most popular sensor groups are listed below:

- MOx (Metal Oxide) [10] – semiconductor sensors, have small dimensions and low price, their main disadvantage is high energy consumption (instantaneous, during the heating of the metal oxide layer) and the fact that the concentration of carbon dioxide is estimated using algorithms, the result will depend on the presence of volatile organic compounds, these sensors are characterized by poor time stability;
- NDIR (Nondispersive Infra Red) [11] – an example of spectrometric measurement, characterized by high accuracy and stability over time, the disadvantage is high energy consumption, relatively large dimensions (compared to other solutions mentioned) and high price;
- Sensors using photoacoustic effect [12] – sensors with small dimensions, high accuracy, average energy consumption, the disadvantage is the high price and availability (new solution on the market).

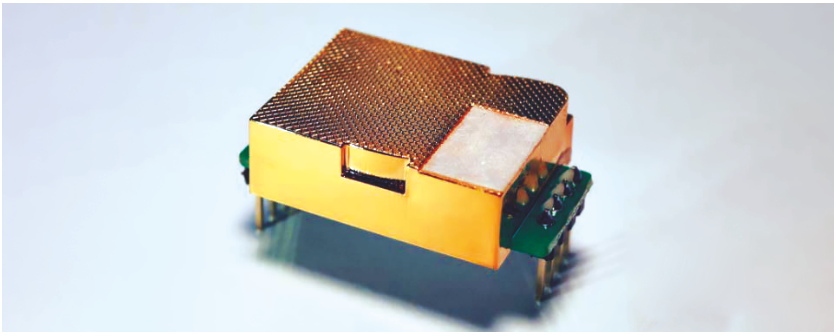

FIGURE 4.1. NDIR sensor MH-Z19C [13]

Based on the features of the above groups of sensors, a sensor was selected to measure the concentration of carbon dioxide. The MH-Z19C sensor (Fig. 4.1) in the form of a Winsen module was selected. It is a sensor from the NDIR group with a measuring range of 400–5000 ppm, accuracy of ±50 ppm + 5% of the read value and declared service life of over 5 years [14].

As in the case of the sensor for measuring the concentration of carbon dioxide, an appropriate system for measuring other values specified in the assumptions was selected in accordance with the criteria. A decision was made for a single-chip sensor BME280 by Bosch [15], which offers the simultaneous measurement of temperature, humidity and pressure. This procedure allowed for the reduction of costs (the need to purchase one chip) and simplification of the electronic circuit.

Device design

The design of the device has been developed on two levels: electronic and software. Each of them meets certain criteria and complements each other at the same time.

Due to the fact that the device is intended to work indoors, it is important that its dimensions allow for its installation in any place, without the need to meet special installation conditions. In addition, taking into account the fact that it would be installed in existing buildings, the advantage will be the fact that there is no need to make a dedicated wired installation.

As shown in Fig. 4.2, the device consists of 4 main blocks. The ESP32 microcontroller was used as the central control system. This 32-bit chip equipped with Wi-Fi [16] functionality is responsible for peripheral operation, data acquisition and wireless connectivity. The choice of Wi-Fi as the transmission medium was dictated by the widespread presence of infrastructure and its low cost. The data is saved on the memory card. The measurement results are displayed on the screen. The ability to communicate with a computer via the USB interface allows to update the software or access data.

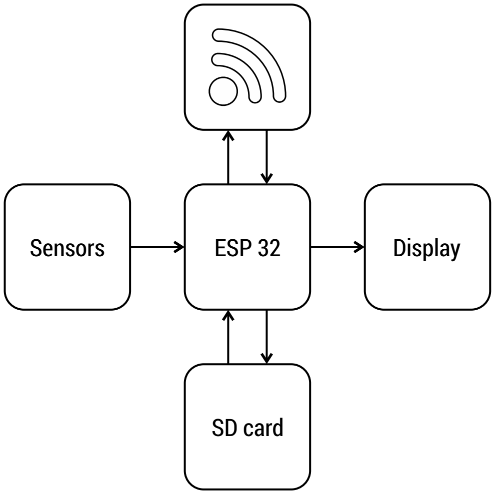

FIGURE 4.2. Block diagram of the most important modules of the device

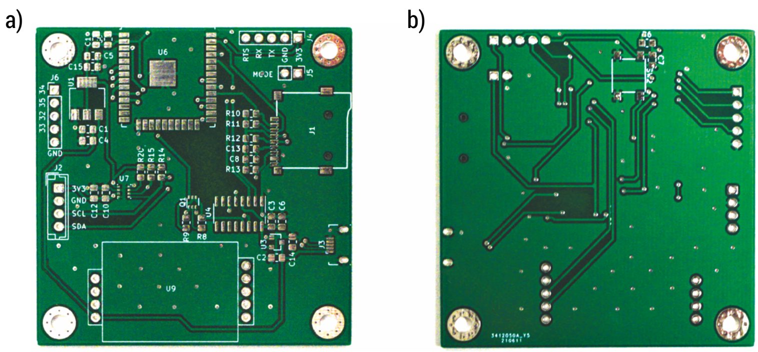

FIGURE 4.3. Printed circuit board, a) top layer, b) bottom layer

The used microcontroller, thanks to its peripherals, provides a wide range of functionalities. An efficient 32-bit processor with Wi-Fi communication allows you to run a web server on the device. This allows remote access to the device. By these means it is possible to view the measurement results via a web browser, configure the device or download the collected data for in-depth analysis. Saving data on the memory card in the form of .csv files allows for easy analysis with commonly used software. In addition, with the help of the network capabilities of the system, it can be connected to home automation systems and more. The MQTT protocol [17] can be used for this purpose.

Having a server with an MQTT broker allows for collecting data from the sensor network (Fig. 4.4). This approach fosters the use of devices in many rooms of an office, house, school or university. However, data can be monitored from one point, without the need to: access a given network or physically access the device. The centralization of information enables them to be easily used to control building automation systems, in this case air conditioning, heating and mechanical ventilation. Since the network consists of individual devices in each room, it allows for zone control and optimization of resource use as well as individualization of operation depending on the requirements set in a given place.

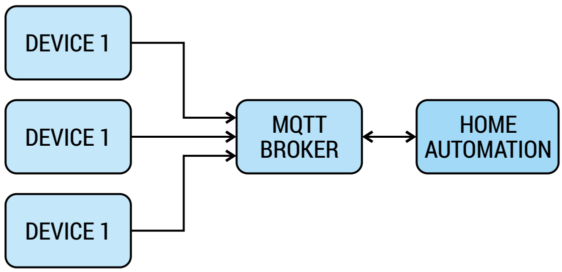

FIGURE. 4.4. Diagram of connection of sensor network with MQTT broker

Results analysis

The best way to verify that the device is working properly is to test it in a practical way. The prototype of the system was tested in various environmental conditions. This allowed for the correct functioning of the device to be confirmed and the results to be confronted with the theory.

The first measurement (Fig. 4.5) was made as a reference measurement. The measurement was made outside the building in an open area in winter. Its purpose was to verify the correct operation of the CO_2 concentration sensor.

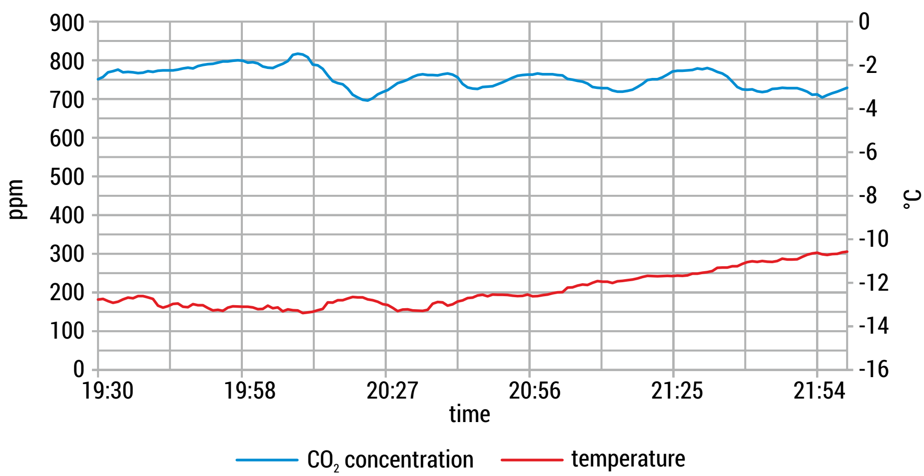

FIGURE 4.5. Reference measurement

The reference measurement (Fig. 4.5) is the reference point to verify that the device is working properly. Currently, the concentration of carbon dioxide in the atmosphere is around 415 ppm (2020) according to the data of Earth System Research Laboratories [18]. Therefore, taking the measurement outside should result in a similar result. The value of CO_2 concentration is influenced by atmospheric conditions, time of day, air pollution, buildings, terrain or time of the year [19, 20, 21].

The full measurement (Figs. 4.6, 4.7, 4.8) was made in a computer lab with an area of about 70 m^2 during a block of classes in which 16 people participated. In the middle of the measurement, there was a break and the room was aired. During the classes, the windows in the room were closed. The measurement was made in winter.

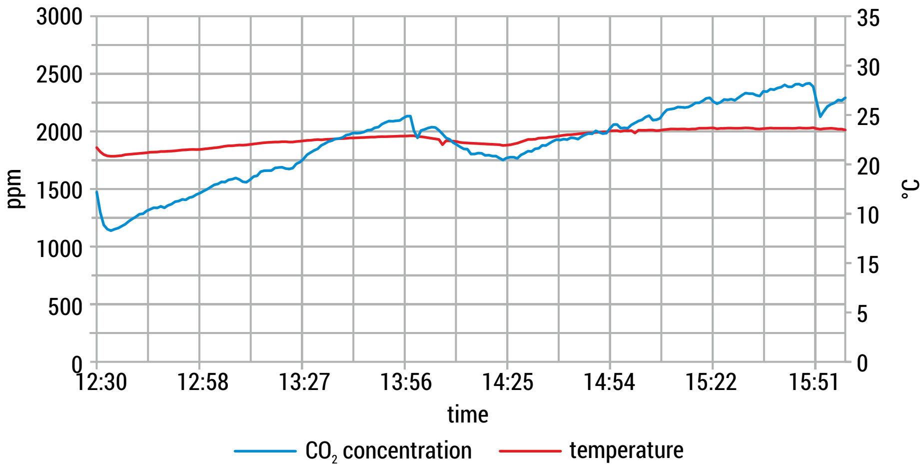

FIGURE 4.6. CO_2 and temperature measurements made during the lesson

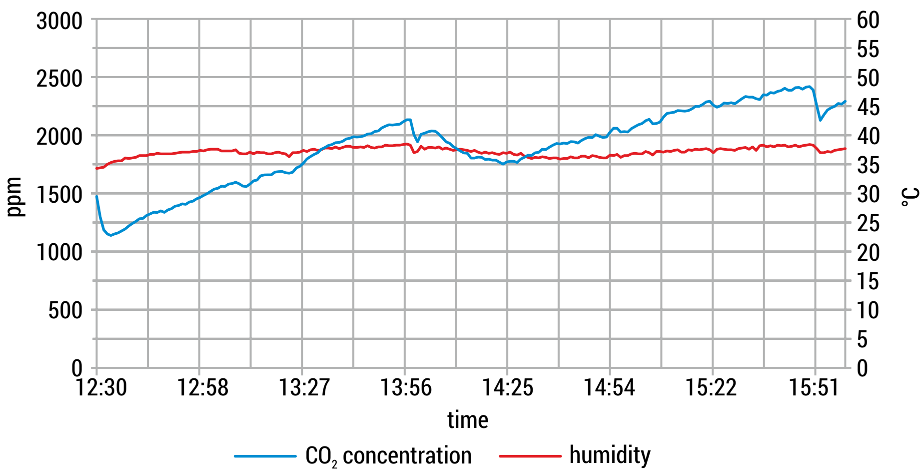

FIGURE 4.7. CO_2 and humidity measurements made during the lesson

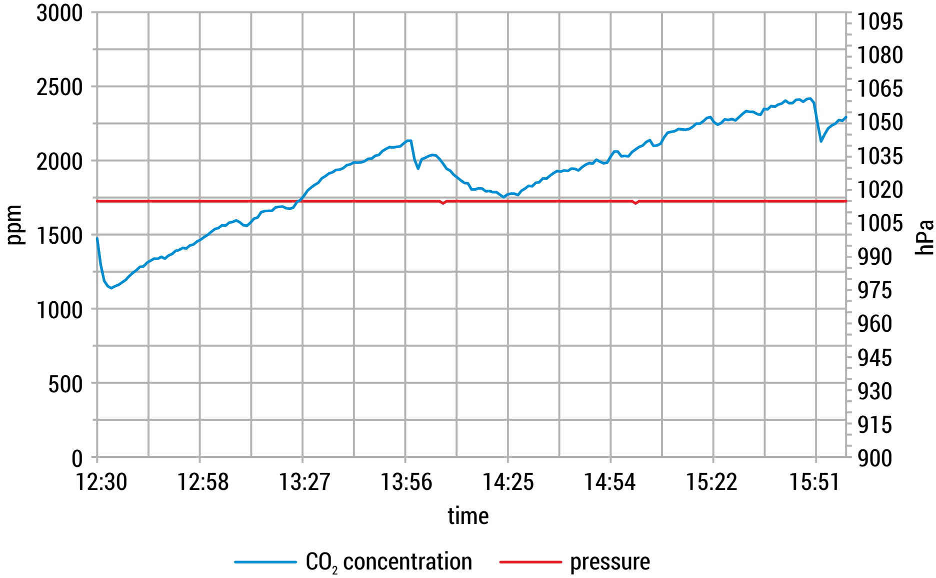

FIGURE 4.8. CO_2 and pressure measurements made during the lesson

After starting the device, the concentration of carbon dioxide suddenly dropped, and then gradually the concentration of carbon dioxide increased until 1:56 pm. After this period, a decrease in concentration was visible, at that moment there was a break between classes. The decrease lasted until 2:25 pm, until the beginning of the next block of classes, after which the value increased again, reaching a concentration of about 2500 ppm. Shortly after the end of the classes, one could notice a decrease due to airing the room. Figure 6 shows a slight correlation between the increase in CO_2 concentration and the increase in temperature. It is worth noting that this is a computer lab, and the measurement took place during the heating season. A similar situation is visible in the case of Figure 7, where there are visible increases in humidity along with an increase in the concentration of carbon dioxide. Pressure values were constant. During the entire measurement period, the fluctuations ranged from about 1100 ppm to about 2500 ppm, the average value was about 1900 ppm. It is assumed that concentrations above 1000 ppm indicate unsatisfactory, and above 2000 ppm – poor air quality [7].

Summary and conclusions

The article presents the design of an IoT device for air quality measurement in order to analyze environmental conditions and integrate with building automation systems. Sample measurement results are shown. Moreover, an analysis of the obtained results was carried out.

The presented solution allows for the measurement of carbon dioxide concentration, temperature, humidity and pressure. Thanks to the built-in Wi-Fi connection, it is possible to integrate the device with building automation systems to control mechanical ventilation, heating or air conditioning. The device allows to collect data on a memory card, which can be used for long-term analysis.

The presented results from the classroom show unsatisfactory conditions during the classes, negatively affecting the comfort of the participants. The simplest solution would be to ensure a continuous exchange of air by constantly opening the windows. Unfortunately, the possibility of airing the room is limited by the weather conditions outside (low temperature, humidity). Alternative solutions in the form of mechanical ventilation with recuperation (heat recovery) require an installation that may not be possible to make or may be expensive.

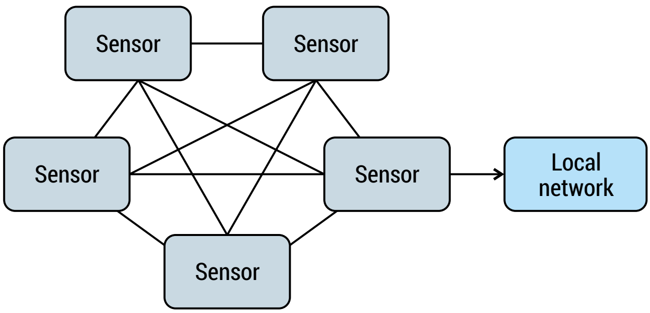

FIGURE 4.9. Example connection structure of devices working in mesh network

The applied solutions allow for the implementation of mesh technology (Fig. 4.9) [22] in order to create a scalable measurement system. This reduces dependence on the range of the available Wi-Fi network. The ESP32 microcontroller also offers access to Bluetooth [16] technology, also in mesh technology. New systems from the ESP32 family by Espressif [23] will also offer connectivity using technologies dedicated to IoT applications. These technologies are Zigbee [24] and Matter [25]. It is also possible to expand the device with additional sensors in order to monitor additional environmental parameters. The used efficient control system, together with the availability of many programming tools from the chip manufacturer, allows for the implementation of various network protocols. This enables integration with various systems available on the market. The research will be continued as the project develops, taking into account the current and future technological achievements and the possibilities of data analysis.

Streszczenie: Świadomość społeczna odnośnie jakości, a zarazem czystości otaczającego nas powietrza rośnie z każdym rokiem. Szczególnie w okresie grzewczym media poruszają te kwestie. Coraz częściej podejmowane są działania mające na celu ograniczenie emisji jego zanieczyszczeń. Niewątpliwie jego stan ma wpływ na nasze zdrowie czy samopoczucie. Prowadzenie przedsiębiorstwa, nie tylko przemysłowego, wiąże się z optymalizacją procesu, tak aby ograniczyć wydatki, a zmaksymalizować zyski. W przypadku pracy umysłowej, na jej efektywność, będzie wpływać w dużej mierze samopoczucie, a zatem jakość powietrza w miejscu pracy. Analogicznie bywa w miejscu nauki, gdzie rezultaty podyktowane są warunkami w których się przebywa. Przedstawiony w artykule projekt urządzenia do monitorowanie powietrza, pozwala na prowadzenie analizy warunków pracy oraz nauki, w celu podjęcia działań ich poprawiających. Urządzenie do monitorowania jakości powietrza w celu optymalizacji warunków pracy oraz nauki.

Słowa kluczowe: jakość powietrza, dwutlenek węgla, IoT, automatyka domowa

Authors: dr inż. Agnieszka Choroszucho, E-mail: a.choroszucho@pb.edu.pl; Mateusz Sumorek, E-mail: mateusz.sumorek@gmail.com; Jakub Żukowski, E-mail: jakubzzukowski@gmail.com; Bialystok University of Technology, Faculty of Electrical Engineering, Wiejska 45D, 15-351 Bialystok, ORCID: 1. 0000-0001-7884-9264

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Chapter 5
The efficiency of Wireless Power Transfer in periodic systems composed of circular coils

Jacek Maciej Stankiewicz
Bialystok University of Technology, Faculty of Electrical Engineering

Abstract: The article presents an analysis of the efficiency of the periodic Wireless Power Transfer (WPT) system. In the analysis circular coils were used. Also, considerations were given for changeability in the number of turns and the distance between the transmitting-receiving coils. The influence of variable system geometry and the frequency on system efficiency was analysed. The Finite Element Method (FEM) with the use of periodic boundary conditions was used for the analysis. Based on the obtained results, it was verified at which system parameters wireless power transfer of the system is possible.

Keywords: wireless power transfer (WPT), numerical analysis, magnetic fields, FEM.

Introduction

The power obtained from the power station in the form of electricity is very costly and the transmission efficiency is very low (~30%), because high tension conductors due to a high energy loss in a high resistive wire. Also, the power station that is running on coal, gas or nuclear materials, uses a lot of these resources to make electricity, is not cost-effective and has trouble associated with environmental issues (e.g. pollution). Due to infrastructure power disruptions are frequent. The indicated problems lead to find alternate solutions connected with transmit and distribute power (electricity). The other problem is the wires for powering home appliances at e.g. house, workplace, schools, because of a reduced range of machines that are prone to failure. Also, while changing the battery of any appliance, the circuit interface can be disturbed and may stop working. Considering the above, the method of a wireless charging system would be beneficial in both economic and social aspects. Many industries are trying to explore the use of electric vehicles or cars in order to the reduce fuel consumption [1, 2, 3]. Also, the WPT system would make a huge impact on the medical field (e.g. pacemaker) [4, 5]. The main focus of researchers connected with the WPT system is to develop a wireless powering mechanism useful for the private sector (e.g. medical, consumer use, industrial) and also for the public sector (e.g. transfer power on a large scale at a low cost and without pollution).

Wireless power transmission (WPT) has become one of the most important research points in this century. Portability is the main motivation for WPT as the number of portable devices is enormously increasing and wired chargers will limit their portability.

Several review works [6, 7, 8] briefly explained the WPT theory, system overview with circuit structure and applications. However, the progress in the resonant coupled system, including the multi-coil WPT structure [9, 10, 11, 12], effects of couplings and frequency splitting on efficiency, as well as human exposure issues [13, 14], has not been extensively studied so far.

In the late 20^{th} century, the near-field inductive power transfer (IPT) [15, 16] became popular because it attained the charging of portable consumer devices. The IPT system can effectively transmit power from a source to a device using the principle of EM induction and is also non-radiative. Inductive chargers, such as those commonly found in electric toothbrushes, charging pads for cell phone [7], operate on this same principle. For the IPT applications of a few kilowatts (kW), like the charging of electric vehicles, almost 90% of transmission efficiency can be achieved by increasing its operating frequency, and over 70% of efficiency is also possible to achieve for low-power (maximum 5 W) mobile phone charging. For low-power industrial and domestic applications, the operating frequency range of the inductive coupled technique is generally from 20 kHz to several MHz.

Nowadays, the emerging application and a growing market of portable mobile appliances, remote charging and powering of these portable devices, the demand for contactless RFID (Radio-Frequency Identification) for security applications and transportation, and power harvesting of battery-free CMOS devices for biomedical engineering – they all are playing the major role in the push-forward of the resonant coupled WPT system.

After the first experiment of a glowing bulb through resonant coils without a barrier and also with a barrier made by MIT (Massachusetts Institute of Technology) in 2007, there have been new advances in the resonant coupled system to make it suitable for commercial applications [17]. In 2008, Intel explored the resonant coupled WPT by using flat coils, which are much easier to fit in mobile devices than the helix coils used in [18]. In [19] an advanced contactless approach simultaneous powering of multiple receiving devices (e.g. laptops, cell phones) was presented. For some research works on resonant coupled WPT, the operating frequency range from 10 kHz to nearly 200 MHz [20] was used.

In opposition to the traditional 2-coil system [21], the 4-coil wireless powering approach is designed by placing two intermediate multi-turn coils between two loop coils. Each loop coil is a form of impedance matching mechanism and acts as a non-resonator to exchange energy between the circuits and intermediate coils [18]. The works [22, 23] connected with multi-coil linked resonant coupled WPT technique have raised interest in 4-coil system for better performance and impedance matching, compared to 2-coil system. The advantage of this approach is that the two intermediate coils are physically set free from circuits, but the main disadvantage is that it requires bigger space than any other transmission structure.

Wireless transmission of electricity to multiple receivers using a single source coil has been described and analysed in [24]. The disadvantage of this approach is the fact that the resonant frequency of coils splits when two receivers are in close enough proximity, and hence lowers efficiency. More difficulty arises with multiple receivers due to the high complexity of the circuit model and a lack of interaction among the coils.

Resonators form an array of coils as a domino [9], and linear resonator arrays [10] are considered, where in the intermediate space between the transmitter and the receiver energy transfer is assisted using several resonators. However, a detailed analysis was performed for a series configuration of resonators, while parallel-series topology of planar coils, acting as a group of energy transmitters and receivers, are still not fully developed.

The power transmission efficiency of the WPT declines at any coupling greater or lesser than its critical value. Therefore, a system to maintain high efficiency without shifting the resonant frequency at coupling distance variation is required. Several approaches, e.g. like optimum frequency adjustment [25, 26], coupling manipulation [27], adaptive matching using multi-loop coils [28] and LC circuits [29], adjusting resonant parameters [30], and use of antiparallel resonant loop [31], have been discussed to deliver power at improved efficiency in the resonant coupled system. Some of the above articles also presented the effect of axial and angular misalignment of the coil, which is the major issue in WPT implementation for portable devices, such as electric vehicle charging [32].

Energy supply or charging of many devices located in close range to each other may be simplified using WPT systems as a grid of periodically arranged coils, which form surfaces for transmitting or receiving the energy. This solution increases density of transferred power and also enables simultaneous powering (using single power source) of many devices (e.g. for charging many electric cars in one parking). The proposed solutions can be used to power either one or multiple independent loads and, in some cases, replace conventional IPT systems. The developed periodic WPT system allows for the simultaneous supply/charging of many low-power receivers, such as mobile devices or sensors repeatedly distributed over hard-to-reach areas.

The article presents a wireless charging system with periodically arranged planar coils. The proposed analysis of the unit cell with periodic boundary conditions does not require full 3D model with many coils [33], where the number of degrees of freedom is huge. A simplified model in the form of the well-known T-type equivalent circuit is an alternative for more extensive matrix formulation [9, 10, 34], where a large coefficient matrix with lumped parameters has to be known. The main purpose of this work is to introduce and study the model, which can be applied to analyze power transfer conditions in the discussed systems.

The article presents a system of periodically arranged transceivers and receivers coils. This proposed system could be used to load mobile devices as the wireless power transfer system. Numerical approach reduces the size and complexity of typically utilized models. By the proposed appropriate selection of load resistance, it was possible to determine the maximum efficiency of the WPT system. Calculations of the exemplary periodic WPT system were performed over a frequency range from 0.1 MHz to 1 MHz. The analysis of the influence of the number of turns and the distance between the transmitting and receiving coils on the efficiency of the system was performed.

Proposed periodic model of the Wireless Power Transfer System (WPT)

A system consisting of a plane of transmitting coils and a plane of receiving coils between which energy was transmitted was considered (Fig. 5.1).

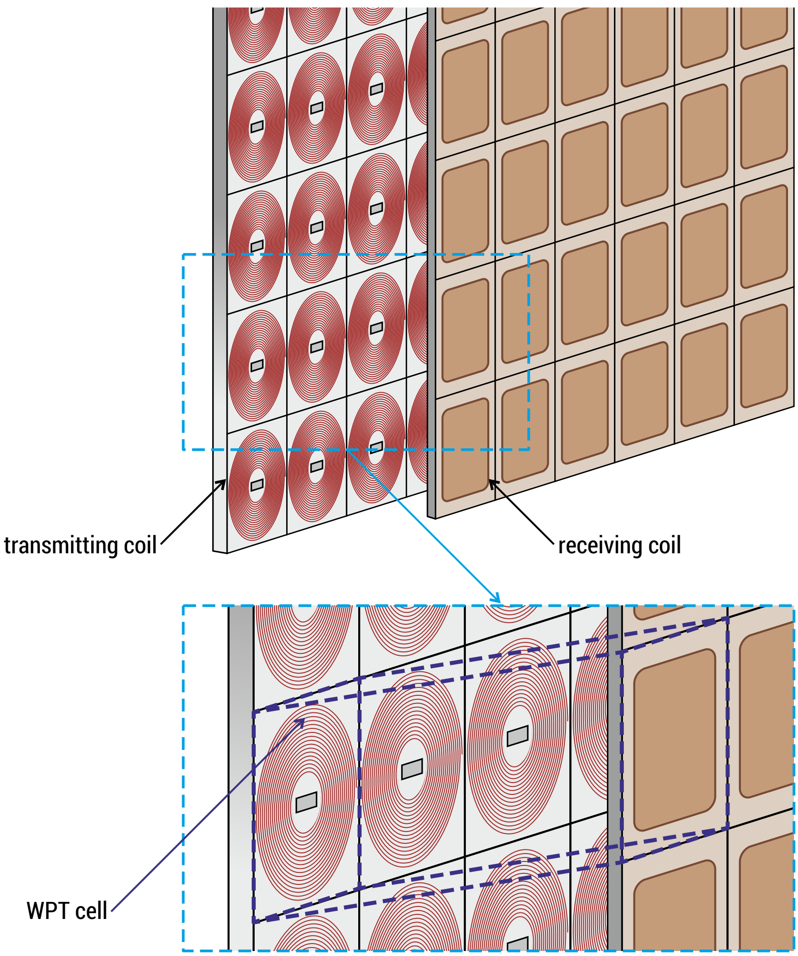

FIGURE 5.1. A three-dimensional view on the WPT system

The WPT cell presented in Fig. 5.1 has external dimensions $d \times d$. The transmitting and receiving coils are placed at a distance (h). The turns are placed on a plastic carcass in which the compensating capacitor connected in series with the coil is located. The three-dimensional distribution of WPT cells leads to the creation of a periodic network, which includes transmitting and receiving surfaces. The WPT cell consists of a transmitter-receiver pair constituting an arrangement of identical coils with a radius r and the number of turns n (Fig. 5.2).

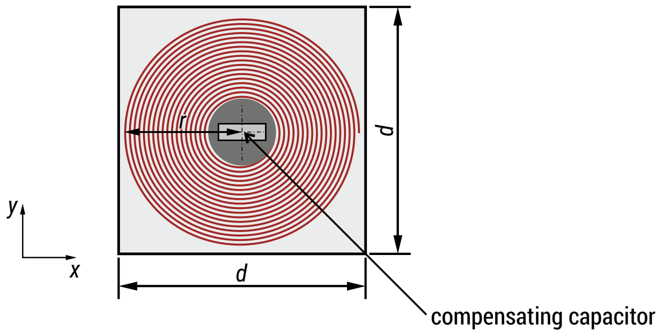

FIGURE 5.2. One circular coil used in the proposed WPT system

The transmitting surface is powered so that each transmitter is connected in parallel with a sinusoidal voltage source with the effective value U. The coils creating the receiving surface are connected directly to the load.

The presented system gives an increase in the density of transmitted power in the area between the receiving and the transmitting surface. The article presents the WPT system, in which it is possible to power many independent receivers, where a set or each WPT cells is assigned a separate load. Each receiver is connected to the load $\underline{Z}$.

Numerical analysis of the WPT system

In the analysis of the WPT system, the FEM method was used. The accuracy of the solution depends on the size of the model, e.g. the number of degrees of freedom (N_{DOF}). A greater number of degrees of freedom allows for obtaining a greater accuracy of the solution. Unfortunately, it causes longer calculation time.

The numerical approach to the analysis of a system composed of many WPT cells requires taking into account: coil geometry, number of WPT cells and elements of the electrical circuit connected to each coil. The coils are wound from several dozen turns, which are made of ultra-thin wires with a diameter (w) and insulated from each other by an electrical insulator of thickness (i). A compensating capacitor can be modelled as a lumped element with capacity (C), attached to each coil.

The WPT system was modelled with periodic boundary conditions (PBC) [35, 36, 37]. This approach allows for simplifying model to a single WPT cell containing a pair of transmitting and receiving coils (Fig. 5.3). The perfectly matched layer (PML) is a place at the top and bottom of the model to imitate infinite dielectric background.

Each transmitting coil is connected to a voltage source with an effective value (U) and frequency (f) that forces the transmitter current ($\underline{I}_{tr}$) to flow. In the receiving coil the source is replaced by a linear load ($\underline{Z}$), which conducts the induced current ($\underline{I}_{re}$).

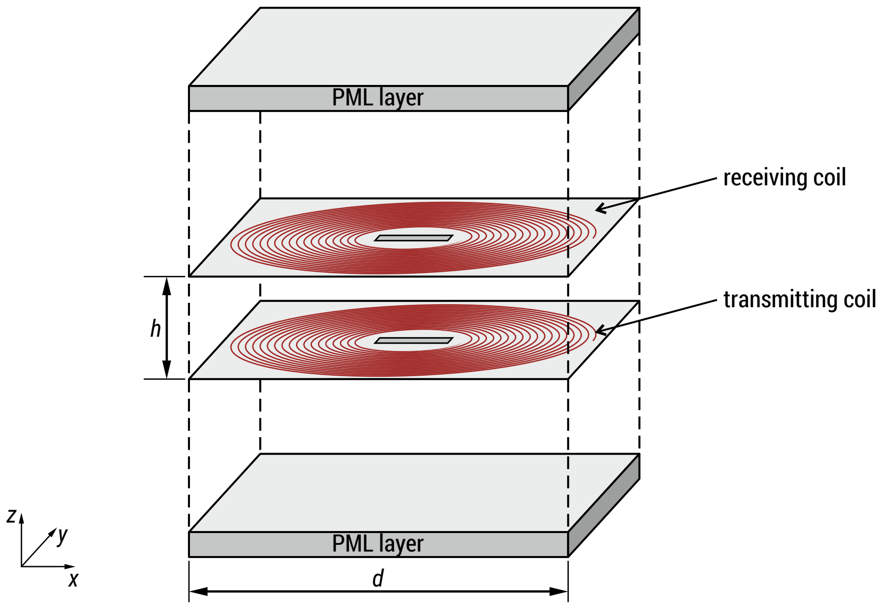

FIGURE 5.3. **Numerical model of the periodic WPT system**

The issue of energy transport in the presented WPT model can be solved using magnetic vector potential in the form:

$$\mathbf{A} = [\mathbf{A}_x \ \mathbf{A}_y \ \mathbf{A}_z]. \tag{5.1}$$

Also was used a description of magnetic phenomena in the frequency domain (Helmholtz equation):

$$\nabla \times \left(\mu_0^{-1} \nabla \times \mathbf{A}\right) - j\omega\sigma\,\mathbf{A} = \mathbf{J}_{ext}\,, \tag{5.2}$$

where:
μ_0 – vacuum magnetic permeability [H/m],
ω – pulsation [rad/s],
σ – conductivity [S/m],
$\mathbf{J}_{ext}$ – external current density vector [A/m^2].

Periodicity conditions on four side surfaces are given in the form of magnetic isolation:

$$\mathbf{n} \times \mathbf{A} = 0\,, \tag{5.3}$$

where $\mathbf{n} = [\mathbf{1}_x\ \mathbf{1}_y\ \mathbf{1}_z]$ is a normal vector to a surface.

The voltage source U with frequency f determines the value of $\mathbf{J}_{ext}$, and taking into account the equation (3) allows to solve the relationship (2) and determine the spatial distribution of magnetic vector potential $\mathbf{A}(x,y,z)$. For this purpose, the FEM method can be used. The compensating capacitor capacity can be determined, e.g. based on parametric analysis of the system at different capacitance values (C). In the case when $\mathrm{Im}[\underline{I}_t] \approx 0$, it is assumed that the system has a resonance state and the selected C is the sought capacity.

Assumption to the analysis

The WPT system was built of identical circular coils. Coil sizes $r = 25$ mm and a different number of turns $n \in \{90, 100\}$ and the distance $hr \in \{12.5, 25\}$ were analysed. Tab. 1 presents parameters of the wire and other values used in the analysis.

TABLE 5.1. Parameters used in the analysis

Parameter	Symbol	Value
Diameter of the wire	w	200 μm
Thickness of wire insulation	i	5 μm
Conductivity of the wire	σ	$5.6 \cdot 10^7$ S/m
Voltage source	U	1 V
Frequency domain	$fmin \div fmax$	100 ÷ 1000 kHz

On the basis of the obtained results for several exemplary periodic WPT systems, the correctness of the proposed numerical model was verified by comparing the active power of the receiver:

$$P_o = Z\left|\underline{I}_{re}\right|^2, \tag{5.4}$$

where: $\underline{I}_{re}$ is a current flowing through the receiving coil. Transmitter power is represented by:

$$P_z = U\underline{I}_{tr}\,, \tag{5.5}$$

where: $\underline{I}_{tr}$ is a current flowing through the transmitting coil. Using equations (4) and (5), the power transfer efficiency was described by:

$$\eta = \frac{P_o}{P_z} 100\% . \tag{5.6}$$

The results were based on the correct selection of Z_e (optimal load impedance) for maximum power transfer efficiency [11]:

$$Z_e = \sqrt{R_c^2 + \left(2\pi f M_{tr}\right)^2} , \tag{5.7}$$

where:
M_{tr} is mutual inductance,
R_c is resistance of an inductor.

Calculation results

The numerical model (Fig. 5.3) was created in the *Comsol Multiphysics program*, using boundary conditions (PML and PBC), and then solved using the Finite Element Method. In order to determine the maximum efficiency transmitted to the receiver, the values of load impedance were calculated taking into account the number of turns and the distance between the coils; and the transmitter power (P_z) (Figs. 5.4, 5.7), receiver power (P_o) (Figs. 5.5, 5.8), power transfer efficiency (η) (Figs. 5.6, 5.9) were presented on this basis.

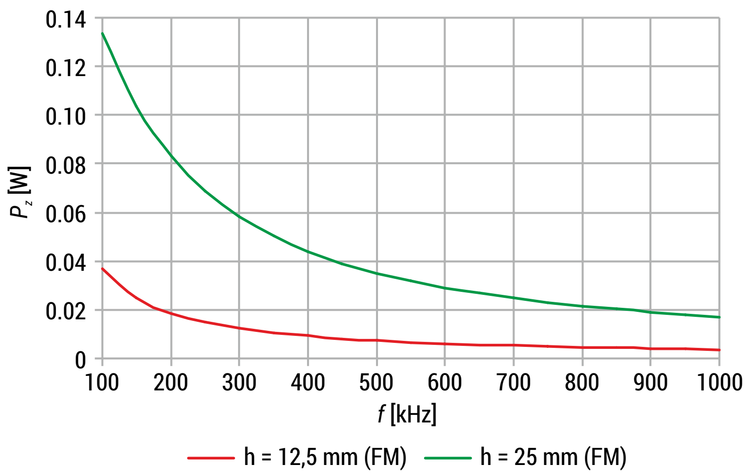

FIGURE 5.4. Results of transmitter power (*Pz*) dependent on the distance at number of turns (*n* = 90)

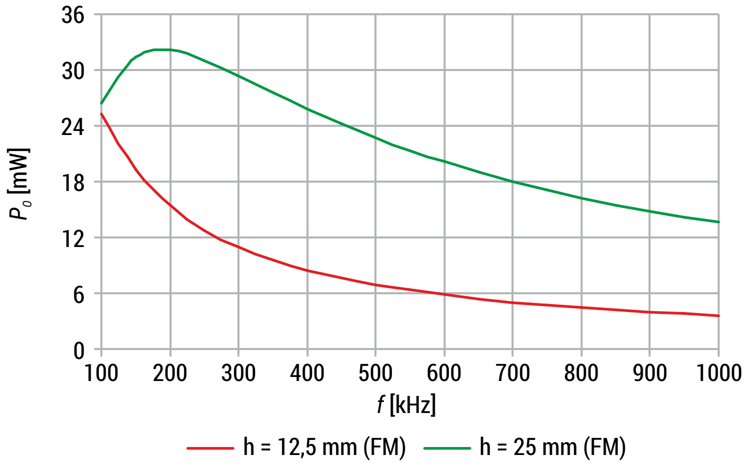

FIGURE 5.5. Results of receiver power (*Po*) dependent on the distance at number of turns (*n* = 90)

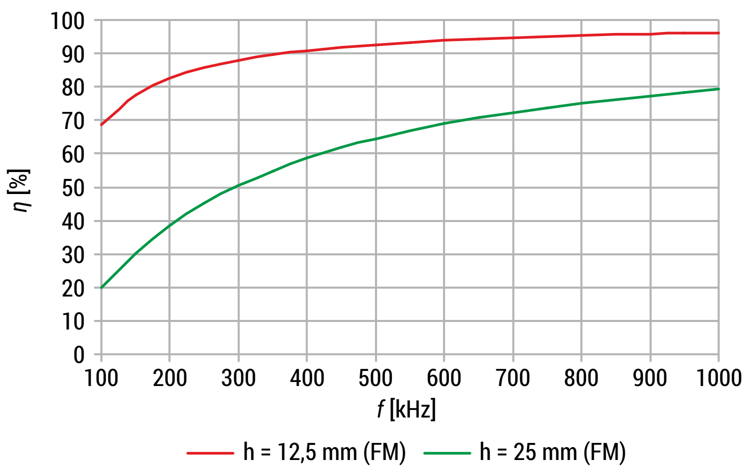

FIGURE 5.6. Results of power transfer efficiency dependent on the distance at number of turns (*n* = 90)

The transmitter power P_z decreases over the entire frequency range, regardless of the number of turns n and the distance h (Figs. 5.4, 5.7). The power P_z is higher at the distance h = r = 25 mm than at the distance h = r/2 = 12.5 mm.

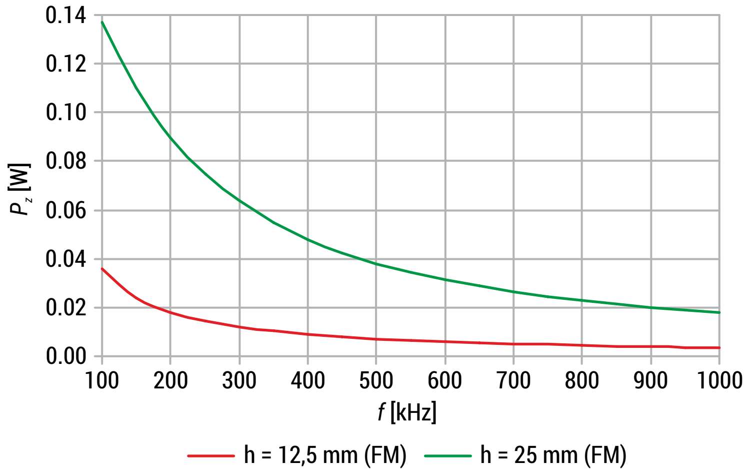

FIGURE 5.7. Results of transmitter power (P_z) dependent on the distance at number of turns (n = 100)

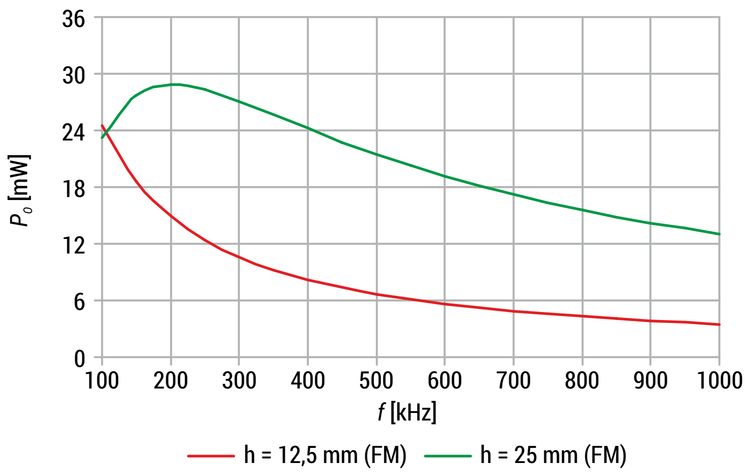

FIGURE 5.8. Results of receiver power (P_o) dependent on the distance at number of turns (n = 100)

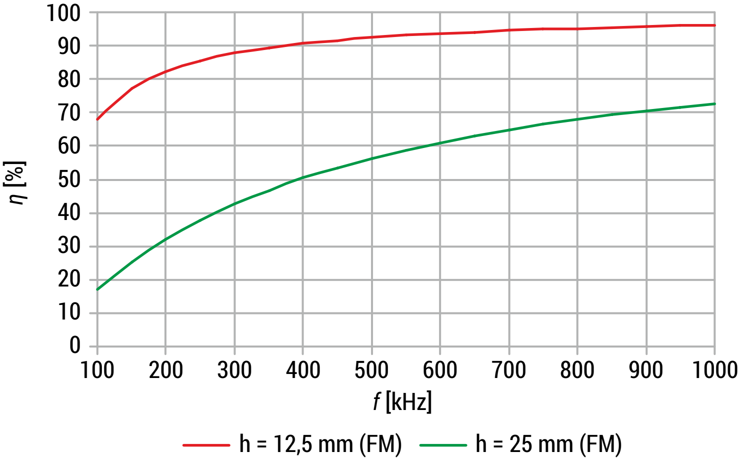

FIGURE 5.9. Results of power transfer efficiency dependent on the distance at number of turns (n = 100)

At the distance h = 12.5 mm the receiver power P_o decreases with increasing frequency. At the distance h = 25 mm the power P_o increases first, and decreases with increasing frequency. By increasing the number of turns, the receiver power will fall. The shape of the receiver power characteristics for both numbers of turns is very similar. As the frequency increases, the efficiency of the system increases and reaches almost 95%. Doubling the distance between the coils reduces the efficiency by up to 50%.

Conclusions

The article presents the numerical approach of solving models of periodic WPT. The maximum power transfer efficiency in periodic WPT systems was analyzed based on exemplary structures with many magnetic couplings between constituent inductors. A different number of turns and distances were taken into account.

The numerical model of the WPT system is an alternative to experimental research. It allows for quick calculations of the efficiency of the WPT system with different geometry of coils. The proposed numerical model makes it possible to estimate the influence of the construction of the coil system and the coil itself on the efficiency of power transmission. By regulating the number of turns and increasing the frequency of the current, it was possible to obtain high power transmission for the loads supplied using the proposed system, without the use of intermediate coils. By proper selection of load impedance, it was possible to determine the power transferred to the receiver and the corresponding efficiency.

Doubling the distance between the coils reduces efficiency by up to 50%. However, increasing the number of turns by 10 results in an increase in the efficiency of the system by almost 5%.

Streszczenie: W artykule przedstawiono analizę wydajności układu periodycznego WPT (Wireless Power Transfer). Do analizy wykorzystano cewki okrągłe. Również uwzględniono zmienność liczby zwojów oraz odległość między cewkami (nadawczą a odbiorczą). Analizowano wpływ zmiennej geometrii układu oraz częstotliwości na sprawność układu. Do analizy wykorzystano metodę elementów skończonych (FEM) z zastosowaniem periodycznych warunków brzegowych. Na podstawie uzyskanych wyników sprawdzono, przy jakich parametrach układu możliwy jest bezprzewodowy transfer energii. (Sprawność bezprzewodowego przesyłu energii w periodycznych układach złożonych z cewek okrągłych).

Słowa kluczowe: bezprzewodowa transmisja energii (WPT), numeryczna analiza, pole magnetyczne, FEM.

Author: mgr inż. Jacek Maciej Stankiewicz, Bialystok University of Technology, Faculty of Electrical Engineering, Wiejska 45D, 15-351 Bialystok, E-mail: j.stankiewicz@doktoranci.pb.edu.pl, ORCID: 0000-0002-1757-2203

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Chapter 6
The shaping of static characteristics of nonhomogeneous planar elements intended for effective heating systems

Adam Steckiewicz, Kornelia Konopka
Bialystok University of Technology, Faculty of Electrical Engineering

Abstract: In the presented article planar heating structures on elastic base are proposed. These novel structures are intended for applications in, e.g., temperature control systems. An influence of electrically heated resistive layer geometry on the thermal properties of the system with a naturally cooled receiver is characterized. The impact of resistive layer geometry is determined, taking into account both thermal and electrical steady-state operating conditions. The results are discussed for a three-dimensional, non-linear numerical model of an exemplary system. The solution of coupled electrical and thermal phenomena is obtained using the finite element method (FEM). Factors which affect the temperature-voltage static characteristics of the exemplary heat receiver are identified.

Keywords: nonhomogeneous composite materials, heating mats, heating efficiency, numerical analysis.

Introduction

Modern composite materials and intelligent structures with adjustable mechanical [1], electrical [2] and thermal [3] properties constitute a group of intensively developed artificial hybrid structures. Their properties can be changed in a wide range to obtain desired parameters such as, for example, the resonant frequency [4] or the temperature in a steady and transient state [5], in an iterative process of adjusting and optimizing the geometry. Among these types of materials a specific group can be distinguished, where thermal properties are modified, and appears as a result of adjustments of proportions and a distribution of two different constituent substances [6, 7]. An example of this kind of hybrid structures are layered/laminar materials, in which at least one layer is heterogeneous and conductive, but the second layer is flexible – it serves both as a carrier and also provides electrical and thermal insulation.

The use of laminar materials in electro-thermal engineering and temperature control systems includes, among others, creating dedicated solutions for heating devices, radiators, or infrared heaters [8, 9, 10]. The dispersed heat generation that occurs as a result of the flow of an electric current through the resistive layer, is characterized by nearly 100% efficiency and possibility of regulating the power, by a simple control system changing the supply voltage. These systems can be used in domestic applications as well as, for example, at particular stage of a production process, in which large-scale (e.g. full-size heating mats) and small-scale components (e.g. local temperature control) are required. The most frequently used resistive materials are metal alloys, such as manganin, constantan, evanohm [10, 11, 12] with a very low resistance temperature coefficient ensuring the stability of heating system parameters, even at relatively high temperatures. This property, however, is associated with non-linear dependence of the dissipated thermal power – and thus a controlled temperature of a heated object – with a change of supply voltage.

The article discusses an influence of the structure of periodic elements, forming the heterogeneous resistive layer of a planar heating structure, on the temperature-voltage characteristics of an exemplary heating system, dedicated to a convectively cooled heat receiver. Two models of the system were considered: linear with constant material coefficients, and non-linear with a dependence of material resistivity of heating elements on receiver temperature. Elements with low and high heating power were investigated. The coupled steady-state analysis of electrical and thermal phenomena was performed using a three-dimensional numerical model, which was solved by the finite element method (FEM).

Model and methods

The electrical phenomena in a considered system are limited to a stationary electric field, which is described by the Laplace equation:

$$\nabla \cdot \left(\rho^{-1} \nabla V \right) = 0, \tag{6.1}$$

where: Ñ – differential Del operator, $V = V(x,y,z)$ – electric potential at a point $P(x,y,z)$ [V], ρ – electrical resistivity [Ωm]. A three-dimensional numerical model was characterized by a nonhomogeneous distribution of resistivity $\rho = \rho(x,y,z)$, generally speaking, different at any point P due to the appearance of a conductor as well as an insulating layer and a dielectric receiver at the top of the system. Moreover, it can be assumed that the value of resistivity has a linear dependence of the resistive layer temperature, hence:

$$\rho = \rho_0 \left[1 + \alpha (T - T_0)\right], \tag{6.2}$$

where: α – resistance temperature coefficient [1/°C], $T_0 = T_0(x,y,z)$ – reference temperature [°C], $T = T(x,y,z)$ – temperature at point P [°C], $\rho_0 = \rho_0(x,y,z)$ – resistivity at the reference temperature [Ωm].

Steady-state thermal phenomena, including electrical heat sources, heat transfer (mostly thermal conduction) and convective heat transfer to an environment, are described by the equation:

$$\nabla \cdot \left[-\lambda \nabla T + h(T - T_a)\right] = Q_V, \tag{6.3}$$

where temperature T is a unknown variable dependent on:

- local distribution of thermal conductivity $\lambda = \lambda(x,y,z)$,
- heat transfer coefficient $h = h(x,y,z)$ of the environment with a constant temperature T_a,

as well as volumetric density of the dissipated power:

$$Q_V = |\mathbf{J}|^2 \rho, \tag{6.4}$$

which directly depends on an absolute value of a current density vector $\mathbf{J}(x,y,z)$.

The occurrence of non-zero value of the power $Q_V = Q_V(x,y,z)$ in the heating layer is the result of heat dissipation due to the electric current of density **J**, forced by regulated voltage U. To determine the distribution of current density **J**, it is required to solve Equation (1). Taking into account the influence of variable resistivity (2), the problem becomes complex and non-linear. Hence, a combination of electrical and thermal phenomena in the conducted analysis is necessary. This is possible through the simultaneous calculation of the local potential V and temperature T distribution, based on equations (1) and (3), including (2), using the iterative procedure in the finite element method.

The design of the heating system is based on the periodic arrangement of resistive elements Ω_e (Fig. 6.1) with adjustable internal geometry. In a structure contained in a cuboid with width and length of $\Delta l_x = \Delta l_y = 5$ mm and height of $\Delta l_z = 0.035$ mm, it is possible to modify a contact length (d_c), path (d_p) and diagonal (d_d) of the element. The presented geometric parameters for the two exemplary elements (Table 6.1) can be selected in order to achieve desired equivalent resistance $R_e = f(d_c, d_p, d_d)$ determining, for the given parameters of a power source, the entire power dissipated in the system.

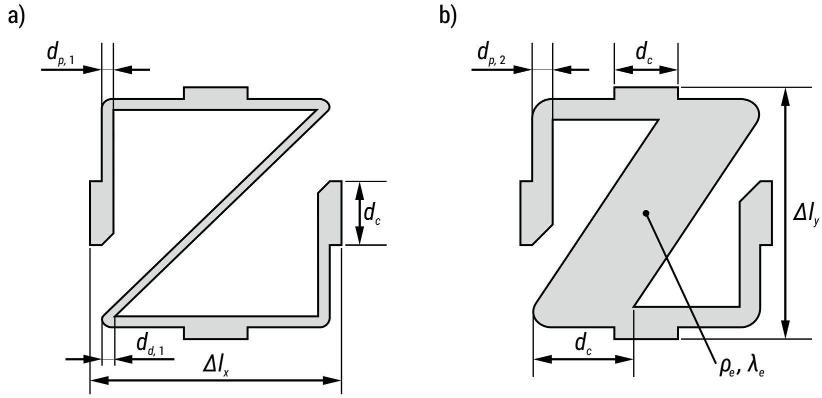

FIGURE 6.1. Heating elements Ω_e: a) lower power variant, b) higher power variant

The object temperature (T_O) at a measuring point is an output parameter of the system, subjected to the adjustment by the controller with a set temperature (T_{set}). This task can be successfully performed by well-known controllers (e.g. PI, PID) that are able to regulate the source voltage. The object temperature results directly from the power dissipated in the resistive layer as well as from voltage U which, in practical implementations, is limited to a certain maximum value U_{max}. Hence, if the source is able to provide sufficient current efficiency (e.g. it can be a typical DC power supply), it is possible to increase the dissipated power (and thus the receiver temperature) by modifying the geometry of the resistive element, so that it will have lower equivalent resistance.

The considered temperature control system (Fig. 6.2) consists of 24 elements located on a surface of non-conductive polymer substrate Ω_B, with thermal conductivity λ_B = 0.3 W/m/°C and dimensions l_x = 30 mm, l_y = 20 mm, l_z = 1 mm. On the resistive layer a rectangular (and also electrically non-conductive) heat receiver with λ_O = 10 W/m/°C and height l_O = 5 mm is placed. The compact, thin-layer heating structure consisting of any number of Ω_e elements, allows for adapting the shape of the periodic heater to almost any application. The electrical and thermal properties can be changed, primarily based on the modification of a single periodic element geometry and placing it (or embedding it) in a thin (e.g. l_z = 1 mm) supporting layer Ω_B. Furthermore, the mechanical strength to bending or cracking and the multiplication of connections between elements (each with 4 contact surfaces with the adjacent ones), increase the reliability of the entire structure, even in the case of possible mechanical stress or damage.

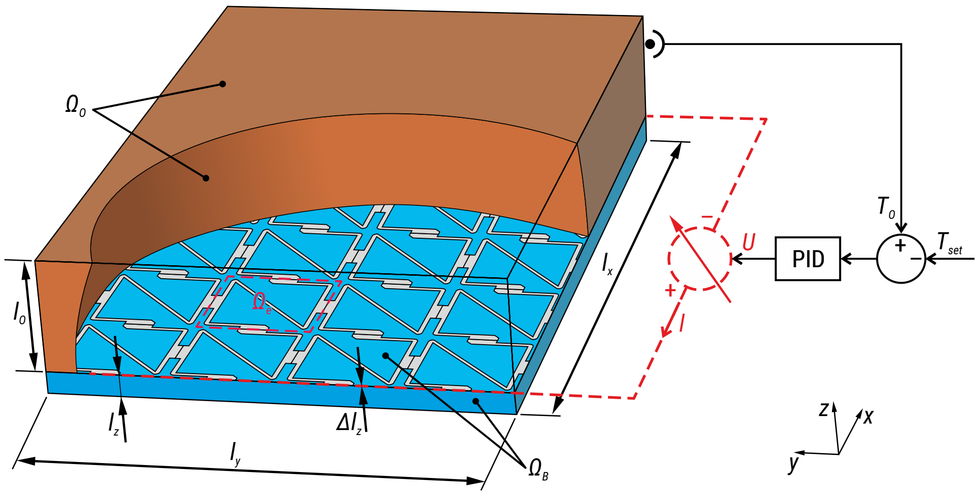

FIGURE 6.2. Heating system with power regulator and a receiver Ω_0 placed on the periodic heating structures, embedded on an elastic insulator Ω_B

TABLE 1. ELectric [11], thermal [12] and geometric parameters of heating elements Ω_e

Variant	ρ_e,0 [Ωm]	α [1/°C]	λ_e [W/m/°C]	T_{max} [°C]	d_c [mm]	d_p [mm]	d_d [mm]
v(1,1)	$2{\cdot}10^{-7}$	0.005	90	250	1.25	0.2	0.2
v(2,1)	$2{\cdot}10^{-7}$	0.005	90	250	1.25	0.4	2.0
v(1,2)	$2{\cdot}10^{-7}$	0	90	400	1.25	0.2	0.2
v(2,2)	$2{\cdot}10^{-7}$	0	90	400	1.25	0.4	2.0

In the numerical model of the system there was assigned, on all external surfaces, the Hankel-Robin boundary condition with a locally determined heat transfer coefficient h, which corresponds to convective heat transfer to an environment with a constant temperature $T_a = T_0 = 25°C$. The system was supplied using an ideal DC voltage source with an adjustable value of U (maximum voltage $U_{max} = 2V$), connected to outer edges of the heating structure (Fig. 6.2 – dashed red lines). Simulations were performed by changing the value of source voltage in a range $0 \div U_{max}$. Four basic variants of the heating system were considered: the first variant $v(1,1)$ refers to an element Ω_e with a lower, and variant $v(2,1)$ to a higher dissipated power with temperature-dependent resistivity. On the other hand, variants $v(1,2)$ and $v(2,2)$ correspond respectively to identical elements, but with a constant resistivity, independent of the system temperature ($\alpha = 0$).

Results discussion

For the discussed variants numerical calculations of the heater model, with an exemplary receiver, were performed. By increasing a supply voltage from 0 to 2 V, the volume distributions of electric potential V (Fig. 6.3) and temperature T (Fig. 6.5) were obtained. Moreover, the dependence of an average absolute (T) and relative (T_w) temperatures of the receiver (Fig. 6.4a), and the absolute current flowing through the heating structure (I) and the relative one (I_w) were found (Fig. 6.4b). Based on the second characteristic, it is possible to calculate the total power dissipated in the system, or equivalent resistance of a resistive path, from the point of view of power source terminals. Thus, on this basis, it becomes possible to analytically estimate electric power consumption or optimal settings of the control system.

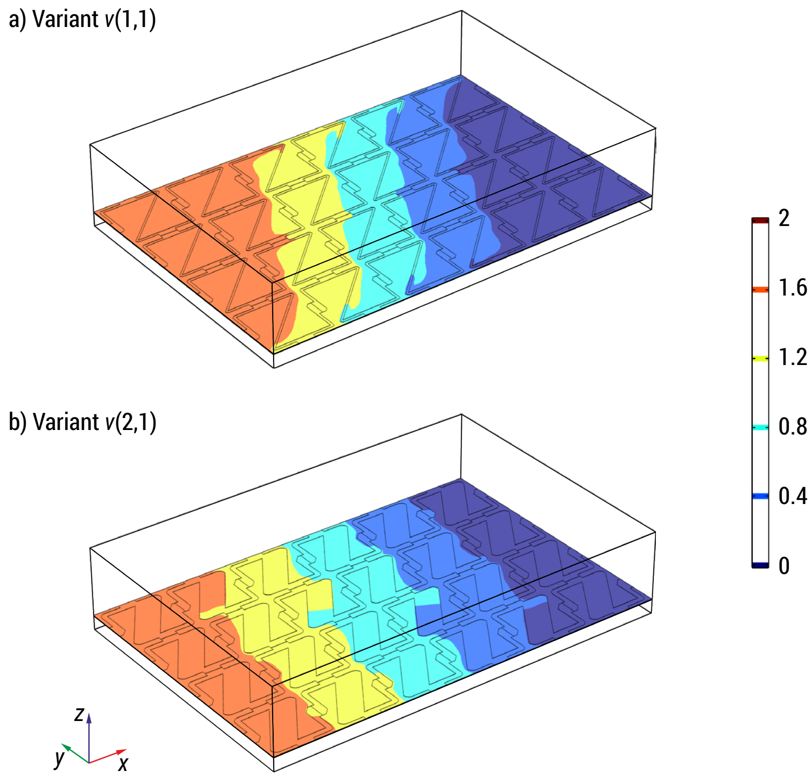

FIGURE 6.3. Electric potential distribution V in [V] on the upper plane of a resistive layer at $U = Umax$ and $\alpha = 0{,}005$ 1/°C: a) system with lower power elements, v(1,1); b) system with higher power elements, v(2,1)

The distribution of an electric field in a resistive layer depends on the geometry of an element. For a structure with higher equivalent resistance (Fig. 6.3a), the isolines of an electric potential do not line up parallel to the *OY* axis (i.e. the edges to which a voltage source is connected). The observed "curvature" is a result of an electric current flowing through also curved resistive paths of the elements. However, for the geometry with higher dissipated power (Fig. 6.3b) the isolines of electric potential are nearly parallel to the *OY* axis, which means that the current flows in a different way than in a previous case. Hence, the distribution of local heat sources on the heating surface will be different. When comparing the potential distributions for elements with $\alpha > 0$ or $\alpha = 0$, no change in distribution or the value of *V* was observed, but only a change in the value of the supply current *I* has appeared.

The dependence of average receiver temperature *T* on the output voltage *U* is highly nonlinear (Fig. 6.4a). The variants with lower (or correspondingly higher) dissipated power, with the two considered values of the coefficient α, have the same geometry but differ in the value of dissipated heat power. This results from different values of currents *I* flowing through the resistive path (Fig. 6.4b), since for $\alpha > 0$ the electrical resistance of the conductor increases with increasing temperature. For example, the Ω_O receiver is heated at $\alpha = 0.005$ 1/°C to a maximum temperature $T(1,1)_{max} = 115$°C, and for $\alpha = 0$ to $T(1,2)_{max} = 150$°C.

The self-occurring power limitation at non-zero α simultaneously leads to the linearization of the $T = \mathrm{f}(U)$ characteristic, when the voltage exceeds a certain threshold value (in this case it is $U \approx 0.7$ V). Then, a relative temperature T_w increase has identical an shape and values, both for the variant of element with lower and higher power (Fig. 6.4a – curves $T_w(1,1)$ and T_w (2,1)). Moreover, in the variant $v(2,2)$, where $\alpha = 0$ is assumed, a permissible system temperature may be exceeded above the specified voltage (e.g. $T_{allowed} = 250$°C), while in the variant $v(2,1)$ elements with the same geometry may be safely supplied in the entire voltage range, since they do not show a sudden increase in power, and thus in the temperature of the object (receiver). Still, according to Ohm's law, the temperature-dependent resistance will affect the shape of a current-voltage characteristic (Fig. 6.4b), where the relation $I = \mathrm{f}(U)$ becomes non-linear.

The temperature distribution on the surface of the resistive layer differs under identical supply conditions for individual geometry variants (Fig. 6.5a, 6.5c). The modification of the current flow path, resulting from the structure of the element, changes both an absolute temperature value (e.g. $T_{max} \approx 123$°C for $v(1,1)$ and $T_{max} \approx 250$°C for $v(2,1)$) and also the distribution of local heat sources. Elements with a higher dissipated power have provided an area of the highest temperatures in the central part of the system (Fig. 6.5c), while lower power elements at opposite vertices (Fig. 6.5a). The distribution of heat sources directly affects temperature distribution within the receiver. However, generally speaking, in both geometrical variants of heating elements, the wide area with the highest temperatures is located in the center of the receiver (Fig. 6.5b, 6.5d) and extends to opposite edges. Nevertheless, the uniformity of temperature distribution at $U = U_{max}$ for the entire receiver volume, defined as $T_{min}/T_{average}$, is high for the variant $v(1,1)$ and equal to 0.94, and for $v(2,1)$ it is equal to 0.96.

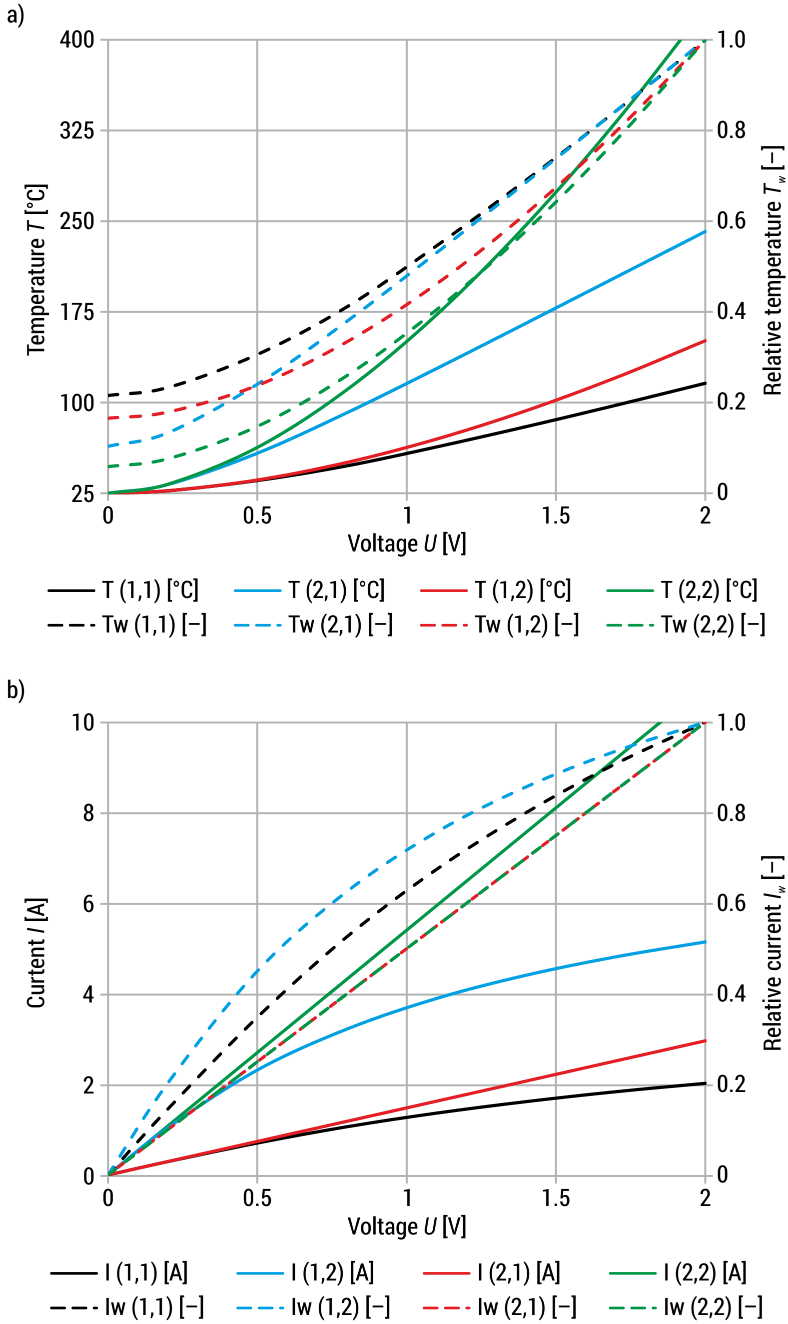

FIGURE 6.4. Absolute and relative characteristics for four variants: a) temperature vs. source voltage; b) current vs. source voltage

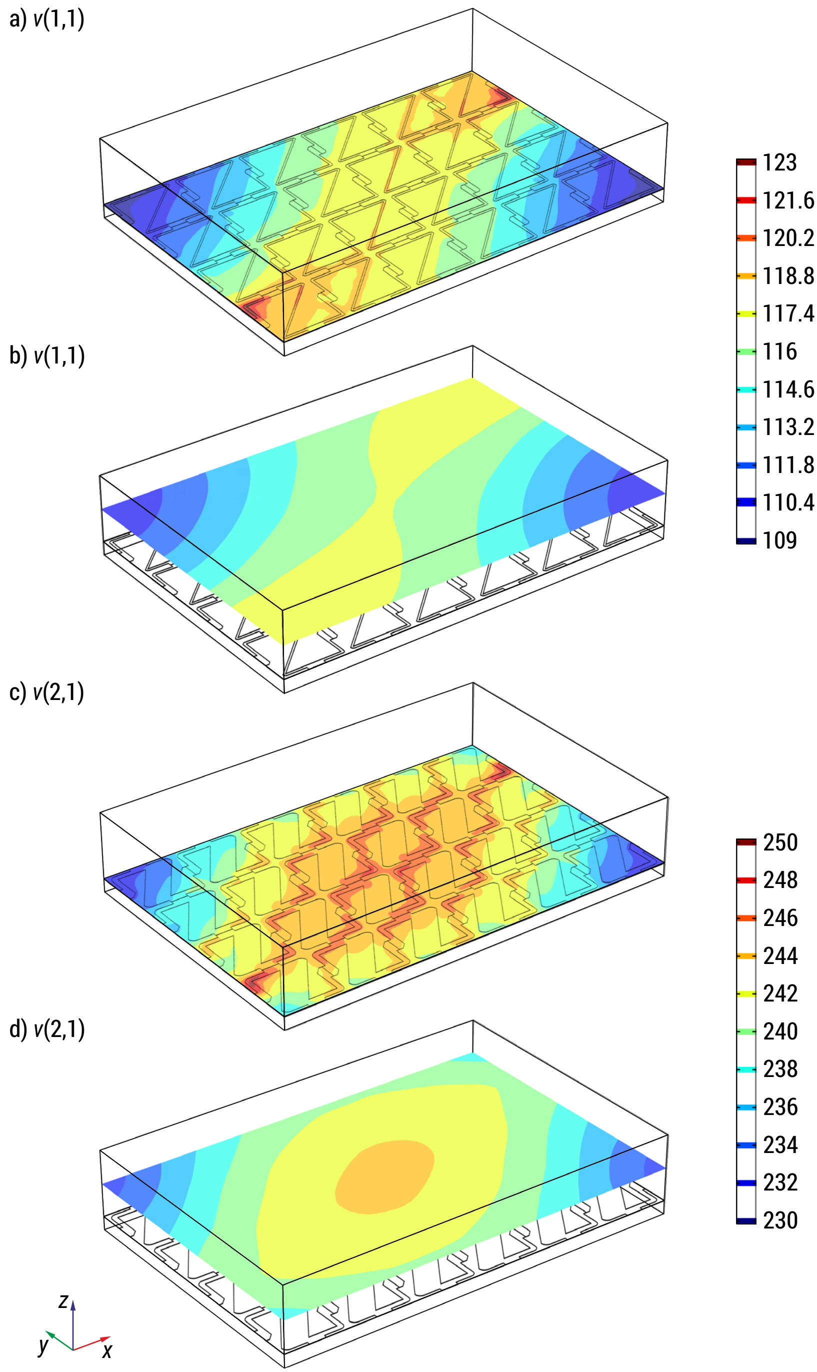

FIGURE 6.5. Temperature distribution T in [°C] at $U = U_{max}$ and α = 0.005 1/°C on the upper plane of the resistive layer for: a) lower power elements, c) higher power elements; as well as in the center of the receiver for: b) lower power elements, d) higher power elements

TABLE 6.2. Linear approximation coefficients of a function T = f(U) as well as relative errors of the linear approximation

Variant	*a*	*b*	$\|\Delta T_{\%}\|$
$v(1,1)$	0.4676	0.0483	8.05%
$v(2,1)$	0.5090	−0.0231	6.90%
$v(1,2)$	0.5102	−0.063	17.04%
$v(2,2)$	0.5708	−0.1854	22.48%

In the last step, an approximation of relative temperature function T_w = f(U), depending on the voltage in the range 0.4 ÷ U_{max} for 4 considered variants, was made. In the case of variants $v(1,1)$ and $v(2,1)$ linear approximation was achieved with the average relative errors $|\Delta T_{\%}|$ of 8.05% and 6.90%, respectively. These values are more than two times smaller than approximation errors of strongly nonlinear functions of variants $v(1,2)$ and $v(2,2)$, in which the assumed resistivity is temperature-independent. The presented results (Table 2) indicate that it is possible to approximate the dependence of object temperature on the source voltage using a linear function, with an average error below 10% in a system with variable resistivity. Hence, the conclusion can be made that with a higher resistance temperature coefficient α and operating temperature T_{set}, the relationship T = f(U) between temperature and voltage U of supply source becomes much more linearized.

Conclusions

In the article a heating system with temperature regulation, arranged of low-power elements, and an exemplary heat receiver was proposed and discussed. The obtained numerical results indicate the ability to adjust the range of dissipated power by a proper change of resistive elements geometry. Material selection of the element, characterized by specific resistivity and the resistance temperature coefficient, has an impact not only on the amount of dissipated heat, but mainly on the shape of static characteristics T = f(U) of the heating system. It is also possible to linearize temperature dependence of the heat receiver on the voltage source by adjusting the shape of the element and using a proper resistive material with a positive temperature coefficient. Linear dependence of the receiver temperature of the source voltage occurs in a wide range of available voltages (i.e. from $0.2U_{max}$ to U_{max}), while the difference between the ideal linear function and the calculated one is less than 8.1%. Higher values of the resistance temperature coefficient and temperature of the heating layer have led to a more ideal linearization of T = f(U) characteristics, but at the same time also reduced the power (heat) dissipated in the conductor.

Streszczenie: W artykule zaproponowano budowę planarnej struktury grzewczej na elastycznym podłożu, przeznaczoną do zastosowań w układach regulacji temperatury. Scharakteryzowano wpływ budowy warstwy nagrzewanej elektrycznie na parametry termiczne układu cieplnego z odbiornikiem chłodzonym konwekcyjnie. Ustalono wpływ konstrukcji warstwy oporowej na termiczny i elektryczny punkt pracy systemu w stanie ustalonym. Dyskusji poddano rezultaty otrzymane dla trójwymiarowego modelu numerycznego, przykładowego układu grzewczego małej mocy z uwzględnieniem nieliniowego charakteru zmian rezystywności elementów grzewczych o dobieranej strukturze. Rozwiązanie sprzężonych zjawisk elektrycznych i termicznych otrzymano za pomocą metody elementów skończonych (MES). Zidentyfikowano czynniki kształtujące charakterystykę temperaturowo-napięciową zadanego odbiornika ciepła. (Kształtowanie charakterystyk niejednorodnych elementów planarnych przeznaczonych do efektywnych układów nagrzewających).

Słowa kluczowe: niejednorodne materiały kompozytowe, maty grzewcze, efektywność nagrzewania, analiza numeryczna.

Authors: Adam Steckiewicz, PhD Eng., E-mail: a.steckiewicz@pb.edu.pl; Kornelia Konopka, E-mail: konopka.kornelia.10@wp.pl; Bialystok University of Technology, Faculty of Electrical Engineering, Wiejska 45D, 15-351 Bialystok, ORCID: 1. 0000-0001-9723-8602

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Chapter 7
Indicators characterizing local energy systems in naturally valuable areas in the light of the requirements of sustainable development

Helena Rusak
Bialystok University of Technology, Faculty of Electrical Engineering

Abstract: The purpose of the article is to select and define values the analysis of which would enable an assessment of the direction in which changes in a local energy system in the naturally valuable areas would take place. The analysis was taken from the perspective of the principles of sustainable development. There were suggested indicators that refer to the social, environmental and economic sphere of the analyzed area. Some of the discussed values refer in the same way to all local energy systems, whereas others are essential only for energy systems that function in naturally valuable areas.

Keywords: sustainable development, indicators, local energy systems, naturally valuable areas

Introduction

Sustainable development is presently, at least in the sphere of declarations, the subject of interest for a majority of decision makers on the international, national and local level. However, in order to introduce in practice the principles ensuing from the premises of sustainable development, it is essential to make decisions on the basis of concrete knowledge and reliable information. Such information is ensured by indicators that are elaborated for monitoring changes in various spheres of man's activity. While analyzing the possibilities of realizing sustainable development policy, one needs to remember that the realization of great national goals requires progress in the realization of small local goals. Therefore, the implementation of the principles of sustainable development on the general national and local level ought to be treated on equal terms. Of utmost importance is this requirement in relation to areas with certain characteristic properties which distinguish them from others that are governed by general principles. Such areas include among others municipalities or counties in the regions with naturally valuable areas which constitute a considerable part of the entity's total area. In most cases the indicators describing changes in energy systems, as regards sustainable development, are elaborated and prepared on the national level. What is overlooked is the analysis of energy systems on the local level, which may lead to taking little notice of those aspects of development sustaining that are important for the local community. A center-oriented approach is in opposition to the premises of Agenda 21, which gives priority to local involvement and pays less attention to the central planning and also demands that local communities ought to be given the possibility to formulate such a policy of sustainable development that is adjusted to the regional expectations [1].

Indicators characterizing local energy systems

It needs emphasizing that depending on the level of socio-economic development of the country in relation to the activities that are conducted in its area on the local level and lead to sustaining development, there arise various expectations and values that will describe these expectations. This requirement also regards the local energy system, which is perceived as a crucial element of sustainable development that is directly related to each of the three basic orders of sustainable development: social, economic and environmental (Fig. 7.1).

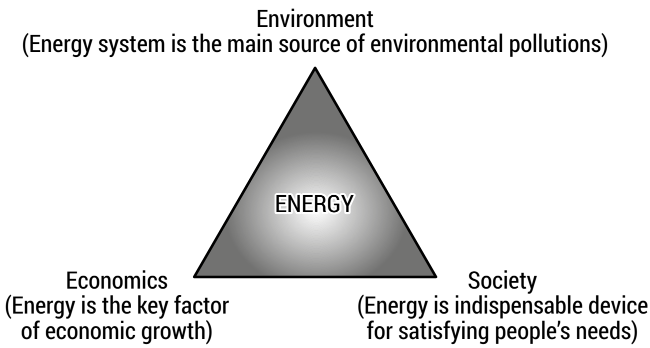

FIGURE 7.1. Relations between energy and sustainable development [2]

It means that while the indicators that are elaborated for national energy systems can be considered as universal on the global level and as capable of describing energy systems of countries on various levels of development and in various social and environmental conditions; the values that describe energy system on the local level require a more individual approach and adjustment to the local needs and requirements. The observations regarding the usage of indicators describing the changes concerning sustainable development show that local communities are not eager to invest in the accumulation of data serving elaboration of indicators as long as they do not sense the relation between the determination of an indicator as the meter of changes that take place on the local scale and yield noticeable advantages. This gives rise to drawing of the following conclusion: local communities ought to participate at all stages of planning, realizing and supervising of a project, including monitoring of the directions of changes that will take place as the consequence of realizing these projects. In other words, all indicators that are prepared for local needs must be combined with local conditions and need to ensure the possibility of participating in the processes that constitute local inhabitants' reaction to these values. Furthermore, the values that are taken into consideration need to reflect the changes that take place in local environmental and economic conditions. Owing to this, the indicators of development sustaining at the local level can be not only simple meters of advancement but they can also stimulate the processes that lead to the better understanding of environmental, social and economic phenomena[1]. This also concerns the local energy system, which is closely related to economy, environment and local social development.

The aim of this article is to analyze the values that could constitute indicators of development of a local energy system in naturally valuable areas (NVAs) from the point of view of sustainable development. This purpose will be realized through the analysis of those indicators that have been suggested for energy systems until now, by checking their usefulness for the local level and by means of selecting special values characterizing energy systems in naturally valuable areas.

The values selected for the description of both the state and changes in the local energy system ought to be characterized by the following features:

- the data used for determining them needs to be relatively easily available and it has to be obtained from the set of conventionally collected statistical data or collected directly, among others, by means of surveys conducted among the group of energy customers selected in an appropriate statistical way;
- the way of collecting data for determining these values must guarantee their correctness;
- data is simple to interpret;
- data is specified in a relatively uncomplicated way;
- data reflects the main problems of energy systems in naturally valuable areas.

The suggested values that are supposed to indicate the state of a local energy system in the context of the requirements of sustainable development can be divided into three groups, i.e. just as it is done in many publications concerning this issue.

The first group comprises values that describe the relation: energy system – local community. This group must comprise:

1) the number of recorded accidents connected with the functioning of the energy system (measured on the basis of the number of recorded incidents);
2) the total number of hours during which there were interruptions in the supply of water for the reasons depending on suppliers, with division into heat energy and electrical energy (measured on the basis of the number of hours/year);

3) the usage of energy per person and the usage of energy per person in a group of households with the lowest incomes (measured on the basis of the value kWh/year).

The first value among the aforementioned refers to the key concept from the social point of view: safety of service and usage of the local energy system. While analyzing this issue, the value describing the state of energy system ought to be divided into two elements:

- the number of accidents per year during service of energy systems (heat energy and electrical energy) related to the number of workers in energy companies in the departments of service and exploitation (workers directly involved in the exploitation and conservation of devices) (measured on the basis of the number of accidents/worker/year);
- the number of accidents per year among the users of heat and electrical energy systems (that result from their usage) in relation to the number of inhabitants (measured on the basis of the number of accidents/inhabitant/year).

Statistics on the national level usually take into consideration fatal accidents, chiefly for practical reasons. However, the safety of service and usage of energy equipment is influenced mainly by external factors that can reduce the hazard despite the fact that the state of energy devices has not changed[1]. Therefore, the safety state of energy systems is best defined by the total number of accidents. Unfortunately, less serious accidents that do not require a physician's intervention are usually neither reported nor recorded. In opposition to the situation on the national scale, in smaller areas it is much easier to obtain information about all the incidents that require a physician's intervention, which can give a better and more realistic view of the safety of service and of the way the local energy system is used. In the energy system the accidents include mostly scald and electric shock, whereas in Poland there are also frequent cases of carbon monoxide poisoning.

The first factor that has an influence on the safety of service of energy systems is knowledge that workers of energy companies have about the safety principles related to the conservation and exploitation of energy devices and also about the compliance with the accepted procedures of conduct. The second group of factors includes technical factors which, in case of the energy system, include the quality of protection equipment. In case of safety of using energy system the division of factors is generally similar. The first important issue is the users' awareness of the existence of potential hazards and familiarity with the ways of avoiding them. The second essential issue is the technical state of networks and installations as well as the protection equipment existing there. All new installations are made in accordance with the bequests

[1] For example, changing the surface from reinforced concrete to wood surface can reduce the possibility of death in case of electric shock. A change of the surface can cause less serious consequences of an accident, but does not improve the quality of the system itself.

of norms, which ensures the acceptable level of usage safety. There remains the problem of old energy installations which were constructed in compliance with the requirements from the time period in which they were made, owing to which they frequently differ from the modern ones and often require careful and regular conservation and repairs that enable restoring or preserving their good technical state.

An essential element from both the social and economic point of view is reliability of supplying energy for customers. In technical calculations there is a number of statistically determined values that describe unreliability of particular elements of the energy system. There were elaborated also detailed algorithms of theoretical estimation of fallibility of the energy system that are based on the analysis of the system structure. However, these methods are too complex to be universally used with reference to all customers in the local system. It would be better to use such algorithms that enable easier estimation and obtainment of data and at the same time that show what is the essence of the issue of value. Thus, it is recommended to use:

- the number of interruptions within a year per customer or equivalent of this value, calculated as the relation between the number of customer interruptions within a year to the total number of customers (*Customer Interruption*),

or

- duration of the time period within which energy was not supplied per customer, or in other words the relation between the duration of interruptions in the supplies within a year (in minutes) and the number of customers (*Customer Minutes Lost*).

Some customers are more sensitive to interruptions in the supply of energy, however, the division of customers into groups depending on their sensitivity to lack of energy and the determination of the aforementioned values separately for each of these groups considerably complicates the practical usage and interpretation of these values and brings additional difficulties related to the formation of groups and to the classification of customers into each of them. Furthermore, the collection of data is becoming more complicated. From the point of view of supervision of the improvement of the reliability of supplying customers with energy, when it comes to customers on the local level, both the aforementioned values meet the expectations of the analysis of work of the local energy system.

In fact, in all the elaborations concerning the values describing the state of the energy system in the light of the requirements of sustainable development into consideration is given to the participation of expenditure on energy in the incomes of households, which is perceived as the measuring instrument of access to energy and energy services[2]. This value is usually analyzed as the average value for all households in the analyzed area and for a certain group of the poorest households.

[2] Energy service – effect that is achieved thanks to the usage of energy and that serves satisfaction of various human needs. Energy service can be exemplified by the fact that everyone likes to feel warmth at home, and in order to achieve this aim and to make radiators warm, gas is combusted in the central heating furnace. In this case energy service is described as the expected temperature

Two of the aforementioned values have their equivalents in sets of indicators of sustainable development elaborated by international scientific organizations.[3] The values which are suggested as measures of reliability of supplying customers with energy, to a certain degree that does not take into consideration fallibility of the intermission of energy, are reflected for the national level by means of indicators regarding primary energy[4]. These values are modeled in the set of indicators for the energy system in a very wide range and in various configurations, whereas the safety of the functioning of the energy system at the national level from the point of view of hazard to health and life of people is described by means of the indicator defined as the number of fatal accidents in the production chain of energy. Unfortunately, this value does not take into consideration accidents among people who are not workers of energy companies, but are only users of the system.

The second group of values describing the state of a local energy system comprises indicators related to the so-called economic order. It is suggested that the group of these values ought to include:

1) the number of working places existing thanks to the functioning of the energy system in a certain area (measured on the basis of the number of working places/year);
2) participation of the area of energy cultivation in the area with soils of V and VI bonitation level (measured in %);
3) participation of local resources of energy in the total amount of used primary energy (measured in %);
4) usage of energy per capita in relation to the average amount of energy used per inhabitant in the country (measured in %);
5) efficiency of the local energy system (measured in %);
6) participation of energy produced from renewable primary energy in the total amount of energy used in the local energy system (measured in %);
7) participation of energy fraction of wastes used for energy-related purposes (measured in %);
8) participation of disposed wastes in the entirety of produced hearth wastes (measured in %);
9) participation of centralized energy systems in the production of heat energy (measured in %);
10) energy consumption in economy (measured in kWh/PLN);
11) average unit cost of electrical energy (measured in PLN/kWh) and heat energy (measured in PLN/GJ).

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in the building. Usually this temperature is approx. 20°, which is satisfactory for a man to feel comfort in terms of warmth. Another example is the possibility of watching television thanks to supplying electrical energy to the TV set.

[3] International Atomic Energy Agency, United Nations Department of Economic and Social Affairs, International Energy Agency, Eurostat, European Environment Agency. Energy indicators for sustainable development: guidelines and methodologies. Vienna: IAEA; 2005

[4] Primary energy – energy in the form not transformed by man, e.g. chemical energy of coal, chemical energy of biomass in natural form not transformed into bio-fuel, energy of water stream, etc.

The value which has a considerable impact on the vision of economic life in the analyzed area is the number of working places generated by the energy system. This value can be considered by the division of it into two elements. One of the elements is the number of workplaces found directly in companies related to the energy system, i.e. in plants that produce energy, distribute it, in companies that sell fuels and energy, produce energy devices and transport fuels, etc. The second element concerns the workplaces that exist thanks to the functioning of the energy system, in companies that are not directly related to this system, i.e. in banks, which provide services for companies of the energy sector, in insurance companies and in inland revenues, etc. This value is to a large degree dependent on the structure of the energy system in the analyzed area. If the analyzed values refer to systems in naturally valuable areas (NVAs), where naturally there are no large companies producing energy, the number of workplaces related to the energy system is affected mainly by the structure of produced energy, and especially by the structure of renewable energy. This value will have a greater value if, for example, higher participation in the production of energy will be seized upon by the production of energy using biomass, whereas smaller participation in the local production of energy will be assumed by the wind power station.

In the indicators that were presented in literature with reference to the energy system at the national level, the role of the energy system as the 'generator' of workplaces was not taken into consideration, which is especially important in the regions with areas protected by law. It implies limitations in running economic activity and thus increases a potential threat of unemployment.

Another value describes the impact of the energy system on agriculture management and concerns the area of energetic cultivation. A local energy system which makes use chiefly of biomass could contribute to the increase in the potential of local agriculture. In general, energetic cultivations are of extensive type – i.e. they do not use large amounts of fertilizers because chemical substances included in the process of energetic combustion of plants would create exhaust fumes and these would pollute the environment. On the one hand, such agriculture would reduce the demand for forest biomass, and on the other hand, it would give the possibility of farming production that yields profits and ensures local development of industry related to the production of various types of biofuels. However, it needs emphasizing that the cultivation of energetic plants ought to take place on soils of low bonitation level. Plantations of energetic plants on soils which would guarantee good harvests of products serving consumption by people would be in opposition to the principles of sustainable development.

Participation of local resources of primary energy, measured in per cents, in the total amount of primary energy used within a year describes the potential and state of using local energy resources. An alternative for an indicator formulated in this way would be the simultaneous usage of two other values:

- amount of primary energy obtained from the outside of the analyzed area in relation to the total amount of primary energy used within a year (measured in %);

- amount of energy produced on the basis of local energy resources in relation to the technical estimates of local energy resources (measured in %)[5].

An advantage of the suggested first version of indicator is the presentation of the issue using one value, whereas the drawback is that the value of the indicator depends on natural energy resources in a certain area, which is not directly reflected in the indicator, whereas energy potential in terms of primary energy does not depend on the adopted energy policy. The usage of the two aforementioned values enables to describe the situation in a more precise way, but also increases the number of values which also need to be analyzed, which makes it slightly more difficult to use them in practice.

The amount of energy used annually per 1 inhabitant (kWh/inhabitant/year) is the universally used value that describes the level of economic growth. In the suggested set of values this indicator was modified and the average amount of energy used per 1 inhabitant in the analyzed area was referred to the average amount of energy that was used per 1 inhabitant in the country. While analyzing this coefficient, it is necessary to become aware of the fact that the value that is lower than 1 does not necessarily mean a worse level of economic growth. In the present level of global economy development it frequently means that in the analyzed area there are used modern technologies in which the added value is created by the technical idea, and not by the energy placed in the product.

A definition needs to be formed for the value that is termed as the efficiency of the local energy system. It is defined as the relation between the energy used by the energy customer to the primary energy introduced into the system (in the form of an abstract fraction or in per cents). The efficiency of the local energy system is affected by the following factors: the degree of energy consumption of the processes of transforming primary energy into fuels; the efficiency of transforming fuels into heat or electrical energy; and the efficiency of sending energy to customers. From the point of view of a sustainable energy system, it would be more beneficial if the numerator of this coefficient included a certain amount of useful energy used by energy customers that would transform it into energy services, which would require knowledge of what is the efficiency of receiving devices functioning in the system. Unfortunately, it appears that in case of statistical information that is presently available, the calculation of an indicator formulated in this way is virtually impossible.

The essence of why the efficiency of the energy system is so essential from the point of view of sustainable development results, among others, from the fact that greater energy efficiency of a system, on the one hand, implies lower usage of non-renewable primary energy, and lower short-term marginal costs of supplying energy to customers,

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[5] Technical local energy resources – energy resources that can be used with aid of available technologies of obtaining and transforming them.

which at the same time constitutes a recommendation to set lower prices of energy. On the other hand, higher efficiency of the energy system also implies lower influence on the environment, especially in the subsystem of producing energy.

The expressed in per cents participation of energy produced from renewable primary energy in the total amount of energy used in a local energy system in principle does not require any comment owing to the fact that this value is used almost in all elaborations concerning indicators of sustainable energy systems. However, the value that requires explanation is the participation of the energy fraction of waste that is used for energy-related purposes (%). One needs to take into consideration both industrial and municipal wastes which are not subject to recycling. In general, there remains the problem of energy management of municipal wastes that contain: fraction of bio-degradable biomass, fraction of plastic and part in the form of glass, rubble, scrap metal, sand and ash as well as water. The first two fractions are flammable substances that decide upon the possibility of thermal transformation of wastes. This issue has been underestimated so far and the energy fraction of municipal wastes is placed on waste heaps. Hence, this problem has an important economic, social and environmental aspect. Naturally, it needs to be solved on a local scale and is directly related to sustainable development of the local energy system. It was included in the group of values of influence on the economic system because the management of energy fraction of municipal waste is connected with the obligation to make considerable investments related to both the selection of some wastes that can be used for energy-related purposes, and to the establishment of plants serving transformation, etc. Furthermore, the plants of thermal conversion of wastes which use the most advanced technologies, e.g. gasification and finally gas combustion, can become environmentally-friendly objects and constitute an essential element of animating the local economic life.

The universally used indicator of sustainable development of energy systems on the national scale is the per cent participation of properly secured solid waste of the energy system. In this case, solid wastes are considered all the wastes in the fuel chain, starting from the wastes created in the processes of extracting fuels, transforming them and ending with the wastes created in the process of combustion. In case of local energy systems in NVAs there are only wastes in the processes of fuel combustion. There is an attempt to define the indicator describing management of these wastes as participation of properly used or secured solid wastes in the entire amount of wastes created in the local energy system. An essential word in this definition is "used", which means that storing of hearth wastes cannot be perceived as the process that is inextricably linked with the creation of energy because there are such branches of economy in which the material created in the processes of combustion can be only a raw material.

Countries that import coal (Denmark, Finland, the Netherlands) use ashes almost in 100% as the substitute of sand and gravel for building roads, surfaces, parking lots, construction embankments for bedding under pipelines and for filling excavations.

On the other hand, when hearth wastes are not used by economic entities, they become stored in waste heaps where they occupy large parts of the area that is later excluded from farming or forest activity.

The value that was shown in the aforementioned set of values for the local energy system as energy consumption of the economy is defined using the following relation: the amount of energy in kWh to the value of production in PLN. It enables the evaluation of energy processes in economy and the analysis of the trends of changes in the energy consumption of the applied technologies, and of changes in the structure of economy. In the elaborations concerning the indicators of sustainable development of local energy systems, an equivalent of the indicator formulated in this way is the efficiency of particular main sectors of economy, i.e. industry, agriculture, trade and services, and it is set as the amount of energy used per unit of the added value created in each sector. At the local level, owing to a lack of data, the indicator formulated in this way would be hard to obtain.

Improvement of energy efficiency of economy (in other words: reduction in the absorbency of energy) has a multidirectional influence on both the economy and the environment. Lower energy consumption directly results in a lower total value of produced energy, and thus it leads to the lower usage of primary energy (including fossil fuels) and a smaller impact of the energy system on the environment. Still, the achievement of lower energy consumption is most frequently related to the necessity to increase outlays on new technologies and modernizations in economy.

Another indicator, i.e. the price of heat and electric energy for target customers in the suggested set of indicators for local energy systems in naturally valuable areas has a classical form and is defined as the average price of energy for the target consumer (in PLN/kWh for electric energy or PLN/GJ for heat energy or energy included in fuels). The problem with the calculation and interpretation of this indicator is that the prices vary depending on the customer in particular groups (e.g. they are different for industrial customers than for municipal and existential customers). This results in the necessity to observe prices for selected types of customers.[6]

Energy prices constitute a stimulus for increasing consumption, or adversely, they may become an inspiration to save energy. Prices are also the factor that decides upon the availability of energy, and to a large degree affects the cost of production, and, as a consequence, has an impact on the competitiveness on the market. Another form of this indicator for the local energy system would be the relation between the prices of energy in the analyzed area and the average price of energy in the country. The analysis conducted on the basis of such a factor could become a stimulus for the highest possible development of the energy system based on local energy

[6] The issue of energy prices viewed as the indicator of sustainable development of energy systems has at least several aspects that would require explanation. However, this problem is too complex to explain it to a satisfactory degree in this publication.

resources. Prices that are either higher than the country's average or lower than the average in the country can become a factor that hinders socio-economic development in the areas that are characterized by unique natural amenities.

From the perspective of areas that are characterized by unique natural amenities, the participation of centralized systems in the production of energy is particularly crucial because these areas usually comprise villages and small towns, where the participation of individual sources of heat energy is very essential. On the one hand, the percentage of the energy produced in centralized sources is related to the influence that the local energy system has on the economy. On the other hand, it affects the influence that this system has on the local environment. The impact on the economy can be seen in the fact that there exists an industrial company that runs economic activity and sells goods in the form of energy. This company must submit various tasks to other economic entities, needs services in offices, banks, insurance companies, pays taxes in which also local budgets take part. A bulk of the economy's influence does not exist when energy is produced directly by customers in their individual appliances.

During the analysis of the influence of the local energy system on the environment in the naturally valuable areas of significance are such features that are not taken into consideration at the national level. Still, the values that are included in the set of indicators of sustainable development of energy systems at the national level in case of naturally valuable areas are frequently either insignificant or impossible to set on the basis of data that is either available or easy to prepare. Therefore, in the suggested set of values for local energy systems in NVAs there are no values that refer to typical systemic issues at a general national level, i.e. the ones concerning the nuclear energy system. There were suggested values that are related to the structure of the energy system and present their influence on nature in a certain area. Such values are essential in Polish conditions because local energy systems in NVAs might have difficulty in the unification of such values on the global scale. The types of problems related to energy in areas that are characterized by high natural value vary from country to country, and in Poland they vary from those, for example, in Finland, whereas completely different problems will be encountered in African countries. There will be differences in conditions, and thus also in the values describing the energy system, for example, in naturally valuable areas and in industrialized areas.

The suggested values that characterize the local energy system within the framework of an environmental order of sustainable development include:

1) participation of wood biomass not obtained from plantation in the entirety of the primary energy obtained from vegetal biomass used for energy-related purposes (measured in % of energetic value (i.e. GJ/GJx100%);
2) amount of created hearth wastes per unit of energy (measured in kg/kWh);
3) amount of emitted air pollutions in relation to created energy (kg/kWh);
4) area of clearings in forests in which power lines are placed in relation to the length of power lines (measured in ha/100km) (or another mechanical intrusion in the environment that is related to the construction and exploitation of energy devices);

5) difference in the level of pollutions in selected neuralgic spots in the summer and winter season in relation to the total consumption of primary energy in the given area (measured in kg/GJ).

The expressed in per cents participation of wood biomass not obtained from plantation in the entirety of primary energy obtained from vegetal biomass used for energy-related purposes is essential owing to the fact that in Poland in the areas where forest wood is accessible, it is used chiefly as fire-wood, which, from the perspective of the renewable energy system, meets the expectations regarding the participation of renewable energy, whereas from the point of view of natural protection, it is in opposition to the expectations. Additionally, part of biomass from forests is obtained in the form of illegal collecting. However, this problem is not as serious as in other countries, for example in South-Eastern Europe or in other relatively poor countries [4]. The greater the participation of forest biomass in primary energy, the less rational, from the point of view of sustainable development of NVAs, is the management of primary energy in this area.

Two other values referring to the relation between the energy system and the environment are listed in many other elaborations concerning this issue in the form of the absolute amount of created pollutions. As suggested in this elaboration, the creation of air pollutions means successively the amount of sulphur dioxide, nitric oxides, carbon dioxide and suspended dust created during the production of an energy unit. Similarly, a frequently used and almost typical value describing the relation between the energy system and the environment is the amount of created wastes per unit of created energy.[7]

A special value which is practically not used in any other sets of values describing the energy system from the point of view of sustainable development and which is essential for the areas of unique natural value is the area of forest clearings in relation to 100 km of power lines. Energetic lines are frequently in forest areas. They are usually of low and medium voltage. The area of clearings caused by the formation of lines in these areas depends on the length of lines in these areas and on the technology of the line, i.e. on the type of sloops and types of wire.

The difference in the level of pollution in selected neuralgic spots in the summer and winter season in relation to the total usage of primary energy in a certain area presents what is the scale of air pollutions emitted by the local energy system because considerable amount of energy in local energy systems is produced as heat energy for the purpose of heating, frequently in individual furnaces that do not have any environmental protection systems. The indicator showing the participation of individual heating systems in the total amount of energy used in a given area shows what is the scale of the phenomenon, whereas the indicator evaluating the difference between the concentration of air pollution in the winter and summer season assesses the quality of these systems. The indicator in the form of such a difference

[7] International Atomic Energy Agency, United Nations Department of Economic and Social Affairs

well describes the state of the heating system in a certain area, especially in the country where the electrical energy system is largely centralized and the local production of electrical energy is marginal.

The analysis of suggested values shows that it is frequently difficult to unequivocally classify particular values into three basic areas analyzed with reference to sustainable development. The issues related to social and economic development as well as environmental issues are linked with each other and depend on one another. For example, reliability of supplying customers with energy is the issue that concerns both the social and economic sphere. If energy is not supplied to the customers of service and trade branches or to the industrial customer, without energy these customers will incur losses which not always can be retrieved, and there will be losses in energy companies due to smaller sales of goods that they produce, send and sell. On the other hand, there may be losses ensuing from the provisions of contracts signed with consumers as regards the expected infallibility level of supply and penalties resulting from defaulting on contract provisions. In situations where energy is not supplied to municipal and existential consumers, suppliers are not burdened with any contractual penalties; the only consequence is that companies lose incomes due to the reduction in sale, whereas consumers are deprived of the possibility to use energy-related services. In Polish conditions this problem concerns especially urban and rural areas, which are predominant in NVAs, in which there are mainly electrical energy overhead lines characterized by a noticeable relation between the reliability of their work and atmospheric conditions. Frequent interruptions in the supplies of energy constitute a considerable burden for the existence in the contemporary world. Consumers are forced to change their daily habits and face forced and uncomfortable situations. Energy shortages at home result in inactivity as well as in worsening of the conditions of having a recess, and frequently lead to the situations where rooms cannot be heated or air-conditioned, and especially when there is no water, etc. Attempts were made to evaluate the interruptions for both the industry and the municipal consumer by means of determination of the readiness to make payments [3]. As the results of the research show, individual municipal consumers were much more interested in the subject than industrial consumers (greater amount of filled in and submitted surveys). On this basis the following conclusion can be drawn: interruptions in the supplies of energy are more burdensome for individual municipal consumers than for the other groups of customers. Furthermore, in terms of quantity they constitute a vast majority. Naturally, it is possible to divide the value describing the reliability of supplying customers with energy into two elements:

- concerning individual customers;
- concerning industrial customers as well as trade and services;

and to qualify the first among them into the sphere of social issues, whereas the second one to economic issues. However, this would complicate the transparency of the values that constitute the basis for assessing the state of the local energy system.

Another example of value that in fact could be classified into the economic, environmental and social order as well is the per cent participation of energy fraction of wastes used for energy-related purposes. The economic aspect was presented in the shortened form above. In this case environmental issues are quite essential and rather clear. On the one hand, the usage of wastes for energy-related purposes contributes to a smaller amount of stored wastes and environmental hazards related to it, whereas on the other hand there emerges a potential hazard (which can be considerably eliminated thanks to the selection of appropriate technology) that is related to the processes of thermal transformation of wastes and emissions into the air as well as to the hazards concerning storing of hearth wastes of these processes. In case of this value there is also a crucial social aspect. It is clear that the thermal transformation of wastes in almost any technology and in every place, irrespective of the character of the area in which such plants could be established, raise serious social resistance. To a large degree they ensue from the lack of knowledge concerning modern technologies.

Similarly, participation of wood biomass not obtained from plantation in the entirety of primary energy obtained from wood biomass can be perceived as equivocal in terms of classification into orders of sustainable development. On the one hand, there can be an easily observed environmental aspect. The greater the participation of biomass from plantation, the less trees are cut down (environmental aspect). On the other hand, this value can be looked at from the economic perspective, i.e. the greater the value of this indicator, the greater influence the local energy system has on the functioning of agriculture (economic aspect).

Conclusions

There are numerous publications concerning indicators of sustainable development, including indicators for energy systems at the national level. However, it is difficult to find elaborations that would raise these issues with regard to local energy systems, let alone local energy systems in such unique areas as naturally valuable areas. It needs emphasizing that the requirements towards energy systems in these areas are special owing to the fact that on the one hand there are required higher standards with regard to environmental protection, and on the other hand due to more difficult conditions of management because of limitations connected with the existence of areas protected by law. Indicators of sustainable development of energy systems in these areas ought to reflect these unique conditions of management and special conditions related to natural protection. Simultaneously, in order to be clear for local decision makers the indicators must have a relatively simple structure. A great number of indicators (both with regard to sustainable development of local energy systems and in general a great amount of dispersed data being the basis for making any decisions) leads to the situation in which their informative role is lost and decision makers are completely unable to make decisions that would use information carried by very complex set of indicators. This elaboration presents 18 such values with traditional division into the values related to social, environmental and economic order. However, it should be highlighted that this division is to a large degree conventional because many indicators directly or indirectly concern more than one of the aforementioned orders.

It is believed that the basic feature that indicators of sustainable development need to have are comparability to other areas (for example, for general national indicators – the possibility of being used by various countries), whereas for naturally valuable areas in the entire world it is essential to take into consideration the specific character of energy systems in various conditions of climate and economy, and also to take into account the conditions in naturally valuable areas that are specific for particular climatic and economic conditions. If there was constructed a system of indicators that would take into consideration all requirements for such areas, the vast majority of indicators for particular areas would be dead because of not being adjusted to the conditions existing there. The indicators presented in this article satisfy the needs regarding the assessment of the relation between the economic-environmental-societal and the energy system in Poland and in other countries of Eastern Europe as well as in countries with similar type of problems regarding the relations between particular elements mentioned above. This paper may become an inspiration for other researchers in various parts of the world, who would wish to supplement the presented set of indicators with other indicators which would show the specific character of naturally valuable areas in other regions of the world.

The indicators presented in this paper can be used for the assessment of energy systems and would equip local decision makers with knowledge concerning the changes that will take place with regard to their local energy-related policies, and also for the assessment of changes that have already taken place. They ought to enable evaluation whether changes in the energy system are in accordance with the premises and requirements of local sustainable development.

Streszczenie: Celem artykułu jest wyselekcjonowanie i zdefiniowanie wielkości, których analiza pozwoliłaby na ocenę kierunku zmian w lokalnym systemie energetycznym na obszarach przyrodniczo cennych z punktu widzenia zasad zrównoważonego rozwoju. Zaproponowano wskaźniki, odnoszące się zarówno do sfery społecznej jak i środowiskowej i ekonomicznej analizowanego obszaru. Niektóre z omawianych wielkości, w jednakowy sposób odnoszą się do wszystkich lokalnych systemów energetycznych, niektóre natomiast są istotne jedynie dla systemów energetycznych funkcjonujących na obszarach przyrodniczo cennych.

Słowa kluczowe: rozwój zrównoważony, wskaźniki, lokalny system energetyczny, obszary cenne przyrodniczo.

Authors: dr inż. Helena Rusak, Bialystok University of Technology, Faculty of Electrical Engineering, Department of Electrical Engineering, Power Electronics and Power Engineering, ul. Wiejska 45D, 15-351 Bialystok, E-mail: h.rusak@pb.edu.pl

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Chapter 8
Electricity management systems and energy efficiency in the context of current standards

Honorata Sierocka, Marcin A. Sulkowski
Bialystok University of Technology, Faculty of Engineering Management,
Bialystok University of Technology, Faculty of Electrical Engineering

Abstract: The article presents two standards related to energy efficiency PN-EN ISO 50001:2012 Energy management systems – Requirements and recommendations for use, and PN-HD 60364-8-1 Low-voltage electrical installations. Part 8–1: Functional aspects – Energy efficiency. In terms of the standards, it was considered how energy management systems represent electricity, and also verified whether the requirements they represent are compatible and not mutually exclusive.

Keywords: electrical efficiency, efficiency management, electrical installations, compatibility standards.

Introduction

The subject of energy efficiency is an urgent and necessary issue. Rising electricity prices and climate change are forcing consumers to minimize their electricity consumption. Standards are created in order to improve the assessment of actions aimed at reducing electricity consumption. Such standards include PN-EN ISO 50001:2012 Energy management systems – Requirements and recommendations for use, and PN-HD 60364-8-1 Low-voltage electrical installations. Part 8–1: Functional aspects – Energy efficiency. The implementation of these standards is intended to help create the systems and processes necessary to improve the energy result of electricity consumers.

The first of these standards relates to electricity management systems and is applicable to organizations of all types and sizes, regardless of the purpose of organizations. This standard discusses how an electricity management system should be built and on what it should be based and how the elements of this system correlate with each other.

The second standard gives guidelines on how to optimize electricity consumption through the design and modernization of new and existing electrical installations. This standard specifically introduces areas where measures should be taken to reduce the electricity consumption of a company.

It is worth checking whether the two standards are compatible and not mutually exclusive since the incompatibility or mutual exclusion of standards and legislation is a frequent problem in technology.

PN-EN ISO 50001:2012 standard

The PN-EN ISO 50001:2012 standard Energy management systems – Requirements and recommendations for use primarily specifies the requirements for an energy management system (EMS). Thanks to such a system, any organization or company can develop and implement an energy policy for its institution. With such a policy, the company is able to define its goals, objectives and an action plan, which, after taking into account legal requirements, will lead to an improvement in energy efficiency.

This standard is based on the continuous improvement principle Plan-Do-Check-Act (PDCA). The cycle of this principle is illustrated in Figure 8.1. As can be seen in the figure, the first step in creating a management system is energy planning, followed by the implementation of the planned actions, checking the effects of the implemented actions and re-analyzing and planning new actions.

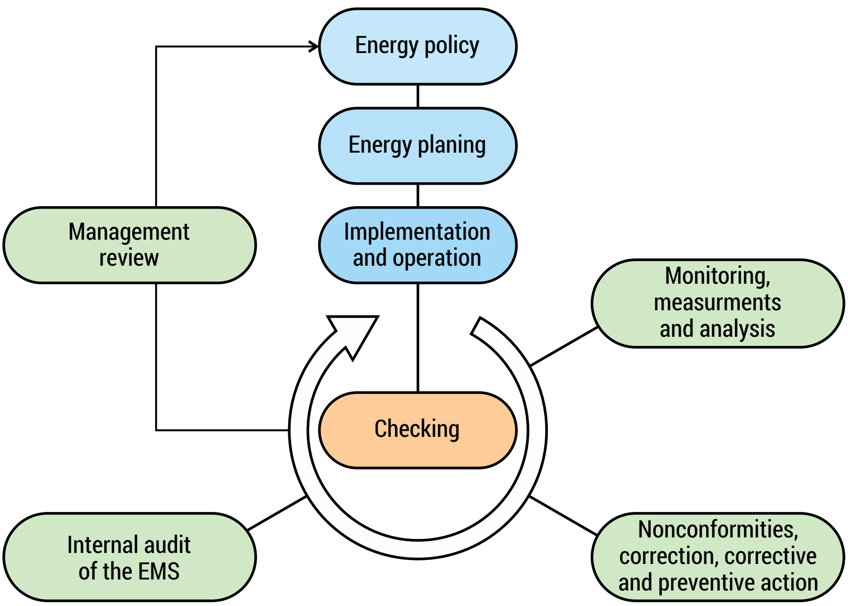

FIGURE 8.1. PDCA management system model

The application of this International Standard contributes to the efficient use of available energy sources, increasing the competitiveness of companies and reducing greenhouse gases. A definite advantage of this standard is the lack of definition of the energy result – the fulfilment of normative requirements does not result in a concrete outcome, as a result two similar companies with similar activities may obtain different energy results and both will be correct.

The general requirements include measures that the organization should take in its management system to improve energy efficiency.

The organization shall:

a) establish, document, implement maintain and improve an energy management system in accordance with the standard;
b) define and document the scope and boundaries of its EMS;
c) determine how it will meet the requirements of the standard in order to continually improve its energy performance and RES.

Above all, the standard indicates that the greatest responsibility related to the energy policy of a plant lies with the company's management. The standard also specifies all the steps that the top management should take to support the energy management system. These are mainly to:

a) define, establish, implement and maintain an energy policy;
b) appoint a management representative and approve the creation of an energy management team;
c) establish human resources, specialized skills or technologies needed to establish, implement, maintain and improve the EMS and the resulting energy outcome;
d) identify the scope and boundaries to be covered by the EMS;
e) communicate the importance of energy management within the organization;
f) make sure that energy objectives and targets have been set;
g) make sure that the energy result indicators are appropriate for the organization;
h) consider the energy result in long term planning;
i) ensure that performance is measured and reported at specified intervals;
j) conduct management reviews.

In addition, a management representative should be appointed to oversee all activities, report on energy performance and on the effectiveness of the EMS in place so as to identify a responsible person.

According to the standard, the company's energy policy should be tailored to the nature, scale and consumption of the organization; it should include a commitment to continuous improvement of energy performance, and it should include a commitment to provide all the necessary resources, both financial and material, to achieve the targets.

In addition, it is worth carrying out and documenting an energy planning process – this will help to analyze the effects that the implementation of specific solutions has had. It should be coherent with the energy policy and lead to a reduction in the energy output. A diagram of conceptual energy planning is shown in Figure 8.2 to define the organization's commitment to the result.

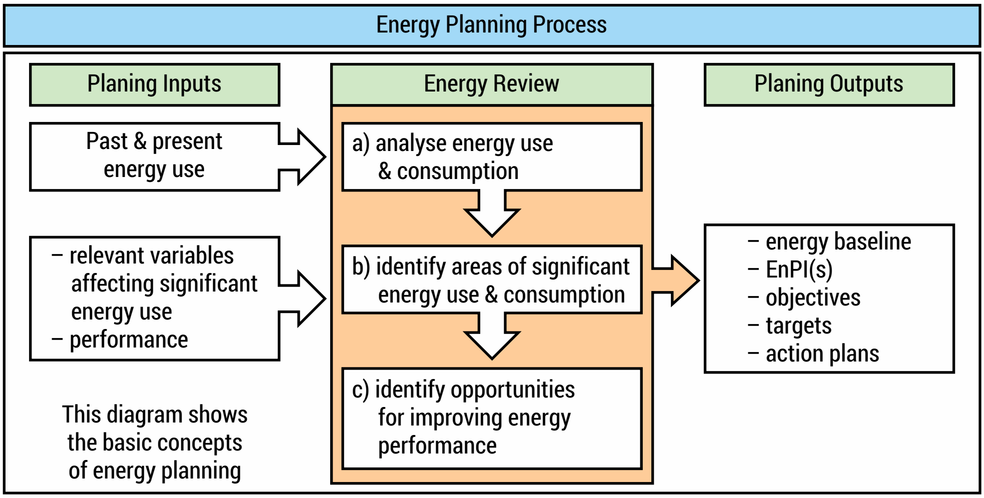

FIGURE 8.2. Energy Planning Conceptual Diagram[1]

An equally important aspect concerning energy management is the fulfilment of legal requirements. The organization must identify, implement and have access to all applicable legal requirements and other currently valid legal documents related to energy consumption and use. The organization should identify how these requirements relate to the organization and its energy management system, and energy efficiency. It should also be remembered that legal requirements should be reviewed at specific intervals so that the organization is always aware of the currently applicable conditions.

For the proper functioning of the energy management system it is necessary to perform energy reviews to make updates. To prepare an energy review, the organization should analyze energy use and consumption by measuring and identifying energy sources, as well as assessing past and present energy consumption. For the correct preparation of the energy review it is also necessary to prepare an analysis of the energy use and consumption. Having such data makes it possible to find solutions to reduce the energy output.

Another important aspect for the preparation of a well-functioning energy management system is the proper training of the staff that deal with it. It is necessary to organize training to improve the skills and knowledge of the staff working on the energy management system. The basis for this is proper education as well as the experience of the staff.

One of the soft skills that should also be developed in management is communication. With the right communication it is much easier to manage the energy system in the organization. The organization should establish and implement a process or communication path where each employee can make comments or suggestions about the ESA. It is also up to the organization to decide whether data related to the energy management system and energy performance are communicated outside the organization, and if they are, the method of such communication must also be established.

The standard also includes how to establish and maintain records related to the energy management system. The organization shall establish, implement and maintain information in electronic, paper or other media so that those who use it have easy access to it. Such documentation should include the scope and boundaries of the SHE, the energy policy, energy objectives and targets, action plans, and other necessary documents. The scope of such documentation depends on the size, scale and nature of the organization concerned. Proper supervision of the documents is also necessary.

The standard also includes a subsection on design. It states that the organization should consider opportunities for energy performance improvement and operational oversight in the design of new, modified and refurbished facilities, system equipment and processes that may affect energy performance. However, the document does not specify exact actions or solutions that can be introduced.

Standard PN-HD 60364-8-1 Low-voltage electrical installations. Part 8–1: Functional aspects – Energy efficiency

One of the primary objectives that electrical designers have when working on a project is to minimize electricity consumption, while maintaining the required level of service and safety. Electricity management should not restrict electrical availability and should not cause difficulties in using the electrical installation. There is now a strong emphasis on reducing losses in the installation system and its use. The document mentioned in the title not only covers new installations, but also refers to existing installations where, as part of a renovation or refurbishment of a building, changes can be implemented and, as a result, energy efficiency can be improved. The standard PN-HD 60364-8-1 Low-voltage electrical installations. Part 8–1: Functional aspects – Energy efficiency shows how to increase energy efficiency in electrical installations.

Optimization of electricity consumption is mainly based on energy efficiency management, which in turn is based on electricity prices and electricity consumption. In existing electrical installations, energy efficiency is checked by carrying out periodic measurements. Measurements of the parameters of electrical installations are carried out throughout the lifetime of the installation and are intended to identify potential problems in the installation, and thus enable corrections and improvements to be made to the installation. Such improvements may be realized by redesigning the installation, or by replacement of faulty or inappropriate electrical apparatus.

The aim of introducing PN-HD 60364-8-1 Low-voltage electrical installations. Part 8–1: Functional aspects – Energy efficiency is to present the requirements and recommendations for the electrical part of the energy management system presented in the ISO 50001 standard. This standard is a set of requirements, recommendations and methods for designing and assessing the energy efficiency of an electrical installation. The electrical efficiency of the installation is classified into levels and the classification scale is shown in Figure 8.3.

FIGURE 8.3. Scale for assessing the energy efficiency of an electrical installation [2]

In striving to optimize electricity consumption, basic principles of electrical design should be followed, which should take into account:

- the energy profile of the load;
- the availability of local generation (renewable energy sources);
- reduction of energy losses in the electrical installation;
- circuit layout for energy efficiency;
- the distribution over time of the customer's energy use;
- the tariff structure of the operator;
- maintenance, quality of service and efficiency of the electrical installation.

The aforementioned measurements of the electrical installation, and more specifically their frequency, should be determined individually for each installation depending on the nature of the facility. The frequency of periodic tests is influenced by the type and equipment of the installation, its use and operation, the frequency and quality of maintenance, factors which may affect energy efficiency and external factors to which the electrical installation is exposed. The results of each periodic inspection should be compared with the previous ones in order to see how the installation's parameters have changed and to identify the elements to be improved. In addition to the basic electrical parameters of the installation, forcing such parameters as human presence, temperature, air quality, daylight, operating time and energy cost must also be taken into account.

The standard in question includes a developed energy efficiency and load management system. It aims to control the energy consumption taking into account loads, local energy generation and storage. When designing or equipping a building, the energy efficiency of loads must be taken into account; priority must be given to the load and the intended use of the installation to ensure an energy-efficient design. A diagram of the energy efficiency and load management system is shown in Figure 8.4.

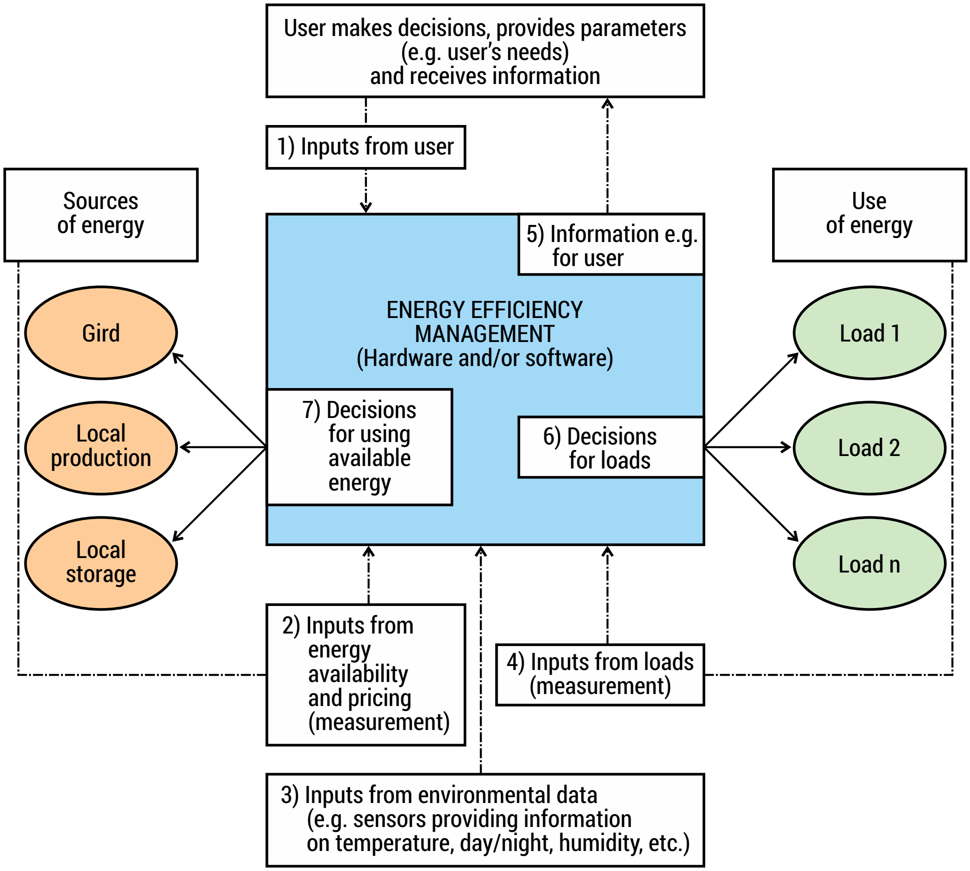

FIGURE 8.4. Energy efficiency and load management system [2]

System loads should be metered with a suitably selected electrical energy sensor, combined with external voltage and current sensors to form a complete metering system for assessing the energy efficiency of the system. Thanks to external sensors, one can anticipate other external factors – forecasts that may affect the management of electricity and which may include weather forecasts to predict temperature and renewable energy generation efficiency, occupancy forecasts, and processing forecasts to adjust generation. It is also important to remember that the meters and sensors used for measurements should be made in accordance with normative requirements so that their indications are reliable. As a result of the continuous improvement of the energy efficiency of the facility, the measurements taken at successive stages of the process will give increasingly smaller discrepancies due to the gradual achievement of the assumed objectives.

The standard also specifies what the electricity management system should be based on. These are:

- end-user selection;
- energy monitoring;
- availability and cost of energy;
- input data from loads, local electricity production and storage, energy sensors and forecasts.

Moreover, the electricity management system should include:

- mesh measurement and monitoring;
- power quality;
- reporting;
- warnings;
- tariff management, if any;
- data security;
- message function to the user and/or the public.

The process of iterative energy efficiency management is illustrated in Figure 8.5. This process shows how the optimization of electricity consumption should proceed sequentially from the consideration of measurements and audits, through the selection of equipment, optimization by means of automation and regulation, through monitoring to the control and verification of activities.

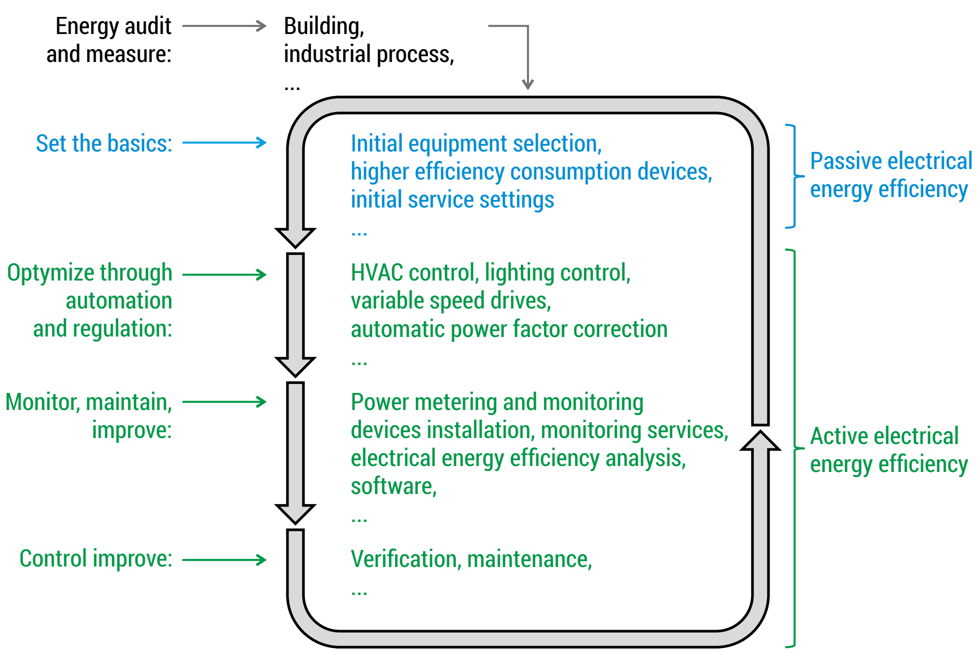

FIGURE 8.5. Iterative process for electrical energy efficiency management [2]

An electricity management system has various objectives, but first and foremost it is to control the overall power and energy efficiency and to test electricity consumption. In addition, its purpose is to determine the impact of forcing parameters, identify control indicators, identify deviations and changes in consumption patterns, and monitor the power quality of the electrical installation. The implementation of an electricity management system is required in buildings with more than 250 occupants or in buildings where electricity consumption exceeds 100,000 kWh/year.

As can be seen, the standard specifies the requirements for an energy management system and discusses the solutions that should be implemented to increase the energy performance of an electrical installation.

Conclusions

Both standards present electricity management systems. The first of the discussed standards presents the system from the general side, based on communication and management. The data contained in the standard are an introductory base for the arrangement of any management system, and the standard itself is structured to enable its implementation in many organizations of different nature. It mainly refers to how a management system should be organized.

The second standard discussed clarifies purely electrical concepts and provides more specific guidelines to be followed for electrical energy management systems. The system presented in the standard can be applied in facilities for various purposes. Specific guidelines are given, which should be followed by designers of new electrical installations and technologists developing a plan for the modernization of existing electrical installations.

The most important aspect is the mutual compatibility of the documents. The standards do not contain contradictory information. PN-HD 60364-8-1 Low-voltage electrical installations. Part 8–1: Functional aspects – Energy efficiency is only a specification of the standard PN-EN ISO 50001:2012 Energy management systems – Requirements and usage recommendations for electrical installations. The guidelines contained in these documents should be implemented in every enterprise in order to reduce electricity consumption as much as possible, and to take care of the surrounding climate.

Streszczenie: Systemy zarządzania energią elektryczną a efektywność energetyczna w świetle obowiązujących norm. W tekście przedstawione zostały dwie normy związane z efektywnością energetyczną PN-EN ISO 50001:2012 Systemy zarządzania energią – Wymagania i zalecenia użytkowania oraz PN-HD 60364-8-1 Instalacje elektryczne niskiego napięcia. Część 8–1: Aspekty funkcjonalne – Efektywność energetyczna. W normach rozpatrzono jak przedstawiają systemy zarządzania energią elektryczną i sprawdzono również, czy wymagania, jakie reprezentują są ze sobą zgodne i nie wykluczają się wzajemnie.

Słowa kluczowe: efektywność elektryczna, zarządzanie efektywnością, instalacje elektryczne, kompatybilność norm.

Authors: dr inż. Marcin Andrzej Sulkowski, Bialystok University of Technology, Faculty of Electrical Engineering, Department of Electrical Engineering, Power Electronics and Power Engineering, ul. Wiejska 45D, 15-351 Bialystok, E-mail: m.sulkowski@pb.edu.pl; mgr inż. Honorata Sierocka, Bialystok University of Technology, Faculty of Engineering Management, Department of Production Management, ul. Ojca Tarasiuka 2, 16-001 Kleosin, h.sierocka@pb.edu.pl, Authors: ORCID: -

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Chapter 9
Determining the maximum power of the WPT system by appropriate impedance selection

Jacek Maciej Stankiewicz
Bialystok University of Technology, Faculty of Electrical Engineering

Abstract: The article analyses the effect of the number of turns and the distance between the transmitter and the receiver surface, as well as the resulting power and efficiency of the Wireless Power Transfer (WPT) system. Each plane contained planar square coils of the same geometry. The article presents a numerical approach to the analysis of this type of systems. The aim of the presented solution is to quickly determine the output parameters (e.g. power, efficiency) without the need to perform experiments. The analysis takes into account the following variability: the number of turns, the distance between the transmitting and receiving coils, and the frequency of the energy source. The results concerned the appropriate selection of impedance to obtain the maximum power of the system. The obtained results allow for a detailed discussion of the dependence of the efficiency and power of the WPT system on the geometry of square coils.

Keywords: wireless power transfer (WPT), magnetic field, Finite Element Method (FEM).

Introduction

One of the commonly used methods of powering mobile devices with energy is charging by means of wireless power transfer (WPT) [1–10].

Increasing the efficiency of the WPT system is possible, among others, by using two additional intermediate coils [2, 11–13]. The advantage of this solution is an increase in system efficiency by 30%. Unfortunately, the disadvantage entails, among others, the need for a larger surface area in order to harmonize the system with four coils located on a square or cuboid-shaped surface.

In the case of loading small devices or cars, it is necessary to use planes containing transmitting and receiving coils [4–6]. The literature describes solutions used for charging batteries while driving a car, which is favorably perceived, for example, in factories or production halls. The WPT system is more and more often used in intelligent constructions, with the use of sensors [20].

The application of WPT applies to many industries and, for this reason, work is still being carried out on new and better solutions and their possible applications.

It is known that each solution requires a multivariate analysis as well as carrying out experiments. However, with the use of analytical and numerical methods, it is possible to initially determine the influence of geometry on parameters related to e.g. with the power of the transmitter and the receiver, and efficiency.

The article presents the WPT solution with the use of square coils constituting the transmitting and receiving surface. Each of the planes was composed of small planar coils of the same geometry, between which energy is exchanged. This solution can be used to power many independent receivers. For this purpose, the FEM numerical method was used to quickly determine the system parameters (e.g. power, efficiency) without the need to perform experiments.

Based on the analysis of the sample model, the possibilities of the developed numerical approach were shown, which takes into account the possibility of modifying the size of the coil, the number of turns and the distance between the planes.

The analysis concerned the influence of geometric parameters of the coil (number of turns, distance between the coils) and frequency on the efficiency of the WPT system and the power of the transmitter and the receiver. By appropriate selection of load resistance, it was possible to determine the maximum power of the WPT system.

The presented WPT system allows for simultaneous supply/charging of many low-power receivers, even on hard-to-reach surfaces (e.g. ceilings).

The analysed model of Wireless Power Transfer System

Using numerical methods (e.g. FEM, FDTD), it is possible to create a model of WPT system and determine the influence of specific parameters on the parameters of the system [10, 14, 15]. To perform such an analysis, it is necessary to create a model and set appropriate boundary conditions.

The analyzed WPT system consisted of many transmitter-receiver pairs that form a WPT cell with external dimensions $d{\times}d$ (Fig. 9.1). The coils on the transmitting and receiving surfaces have the same dimensions: radius (r) and number of turns (n_t). The transmitting surface consisting of the transmitting coils is connected in parallel with the sinusoidal voltage source (U).

The presented numerical model of the WPT system enables the selection of power conditions depending on the imposed requirements. This solution also allows for the simultaneous supply of many independent receivers, where the set or each of the WPT cells is assigned to a separate load.

The proposed periodic WPT system consists of two surfaces (transmitting and receiving). Each surface contains a set of coils with the same winding direction (Figs. 9.1, 9.2).

The analysed square planar coils are wound with several dozen turns, which are made of ultra-thin wires with a diameter (*w*) and insulated from each other by an electric insulator with a thickness (*i*).

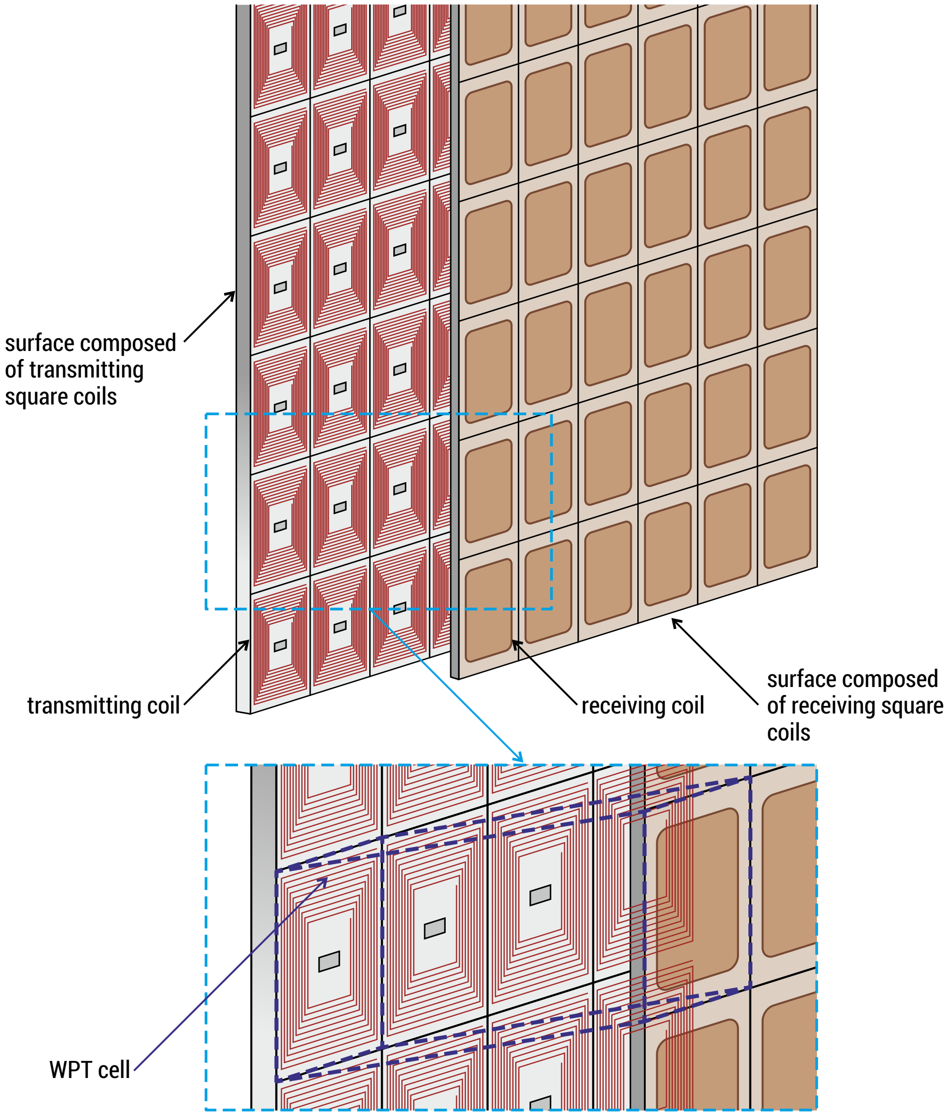

FIGURE 9.1. The analysed WPT system with a transmitting and receiving surface

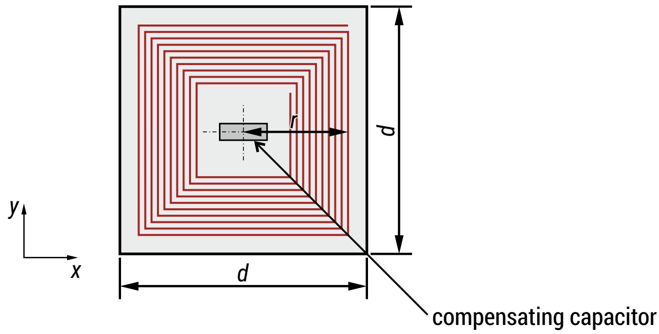

FIGURE 9.2. One of the many square coils that make up the transmitting and receiving plane

The compensation capacitor can be modeled as an element with concentrated capacitance (*C*). A voltage source (*U*) with a frequency (*f*) is connected to each coil and the current flows through the transmitter ($\underline{I}_{tr}$). A receiving coil connected to a linear load *Z* carries the induced current ($\underline{I}_{re}$).

Periodic boundary conditions (PBC) were used to reduce the model to one WPT cell. On the other hand, a perfectly matched layer (PML) was placed on the upper and lower surface of the WPT cell to imitate the dielectric background [10, 14] (Fig. 9.3).

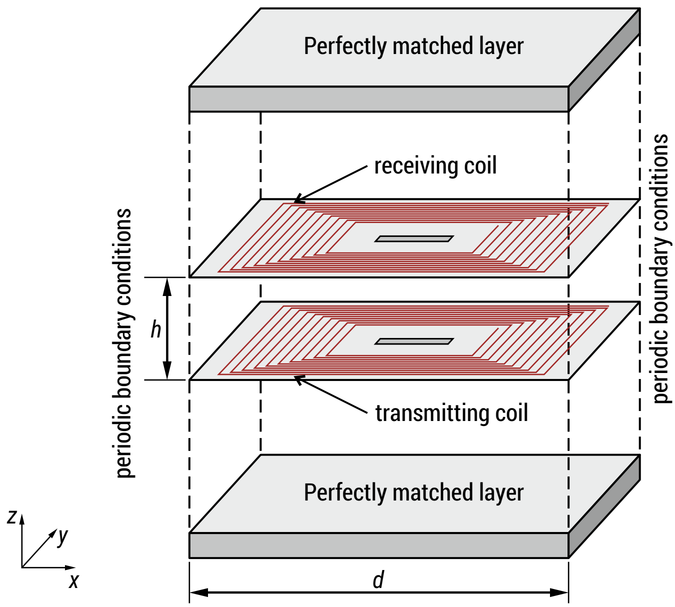

FIGURE 9.3. Three-dimensional view of one of the WPT cells

The issue of energy transport can be solved using magnetic vector potential:

$$\mathbf{A} = [\mathbf{A}_x \ \mathbf{A}_y \ \mathbf{A}_z], \tag{9.1}$$

and using the Helmholtz equation:

$$\nabla \times \left(\mu_0^{-1} \nabla \times \mathbf{A}\right) - j\omega\sigma\,\mathbf{A} = \mathbf{J}_{ext}, \tag{9.2}$$

where:
ω – pulsation [rad/s],
σ – conductivity [S/m],
μ_0 – permeability of an air [H/m],
$\mathbf{J}_{ext}$ – external current density vector [A/m^2].

In order to verify the adopted assumptions, an analysis of exemplary variants of the proposed solution of the WPT system was performed. For this purpose, the transmitter power was determined:

$$P_o = Z\left|\underline{I}_{re}\right|^2 . \tag{9.3}$$

Additionally, the transmitter power was determined:

$$P_z = U\underline{I}_{tr} . \tag{9.4}$$

Using equations (3) and (4) the power transfer efficiency was represented by equation:

$$\eta = \frac{P_o}{P_z} 100\% . \tag{9.5}$$

The analysis concerned a comparison of P_z and P_o and efficiency for proposed variants of the WPT system. The results concerned the appropriate selection of impedance Z_p to obtain the maximum receiver power of the WPT system [16–19]:

$$Z_p = R_c + \frac{\omega^2 M_{tr}^{\;2}}{R_c} , \tag{9.6}$$

where:
R_c – resistance of the inductor [Ω],
M_{tr} – mutual inductance [H/m].

Parameters of the analysed models of the WPT system

The analysis concerned variants differing in the number of turns and the distance between the surfaces (transmitting and receiving) (Tab. 9.1).

TABLE 9.1. Geometrical parameters of models

radius (*r* [mm])	number of turns (*n_t*)	distance between coils (*h* [mm])
10	20	5 and 10
	30	5 and 10

The parameters were accepted for described calculations: wire thickness $w = 200$ µm, insulation thickness $i = 5$ µm, conductivity of the wire $\sigma = 5.6 \cdot 10^7$ S/m, voltage source $U = 1$ V. The analysis was performed for a wide frequency range: from 0.1 MHz to 1 MHz.

Calculation results

The source power (P_z), the receiver power (P_o), and power transfer efficiency (η) are presented in the below figures. Transmitter power, receiver power and power transfer efficiency were calculated within frequency range from <0.1–1> MHz. The numerical model was created in the Comsol Multiphysics program. Using the FEM method, a numerical analysis was performed. The analyzed model contained 231460 degrees of freedom.

The source power (Figs. 9.4, 9.7), the receiver power (Figs. 9.5, 9.8) and power transfer efficiency of the WPT system (Figs. 9.6, 9.9) are presented.

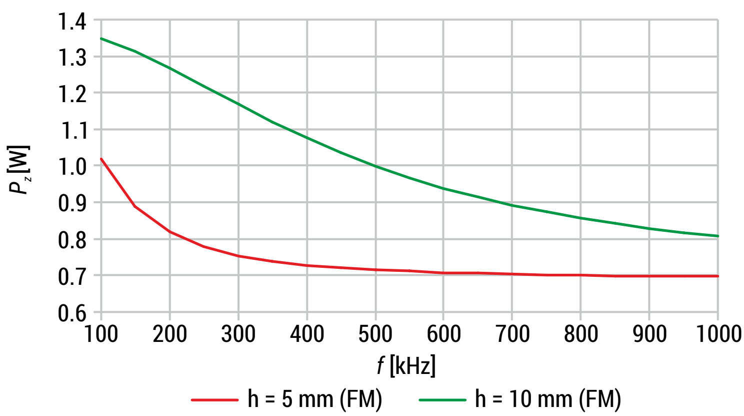

FIGURE 9.4. Results comparison of the source power (P_z) depending on the distance *h* (*n_t* = 20)

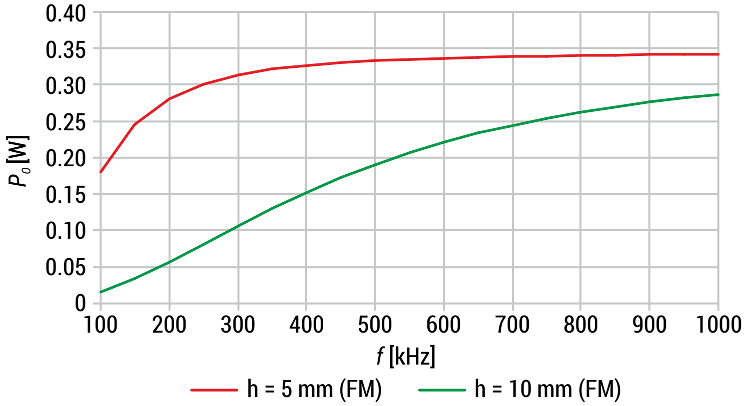

FIGURE 9.5. Results comparison of the receiver power (P_o) dependent of the distance *h* (*n_t* = 20)

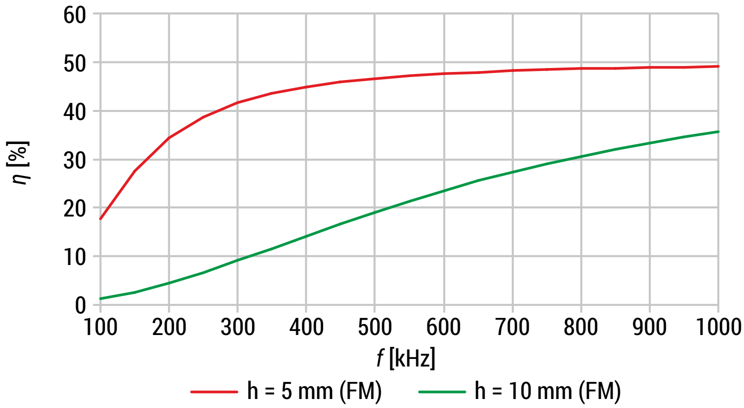

FIGURE 9.6. Results comparison of power transfer efficiency depending on the distance *h* (*n_t* = 20)

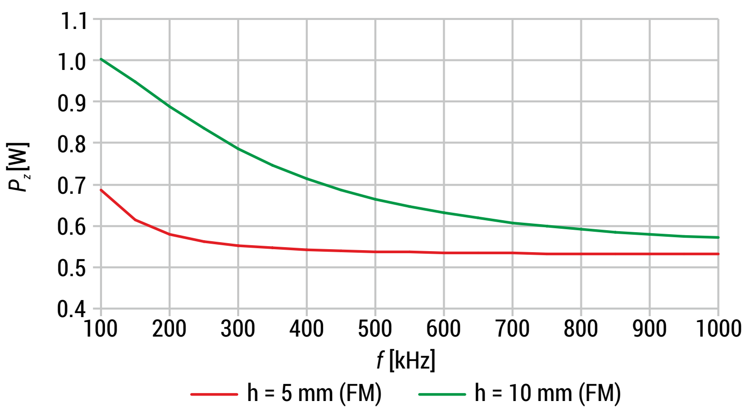

FIGURE 9.7. Results comparison of the source power (P_z) depending on the distance *h* (*n_t* = 30)

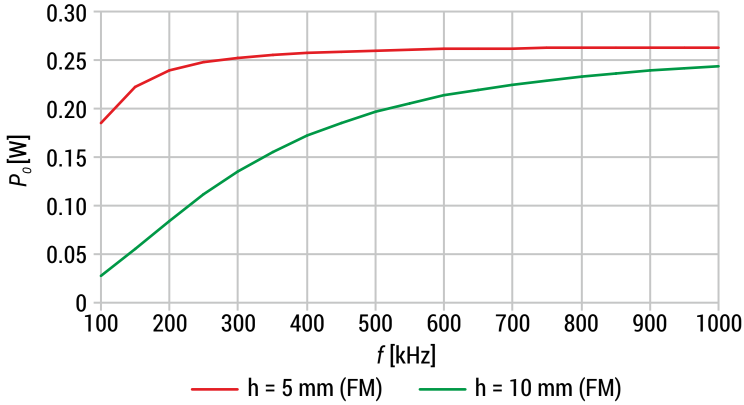

FIGURE 9.8. Results comparison of the receiver power (P_o) depending on the distance *h* (*n_t* = 30)

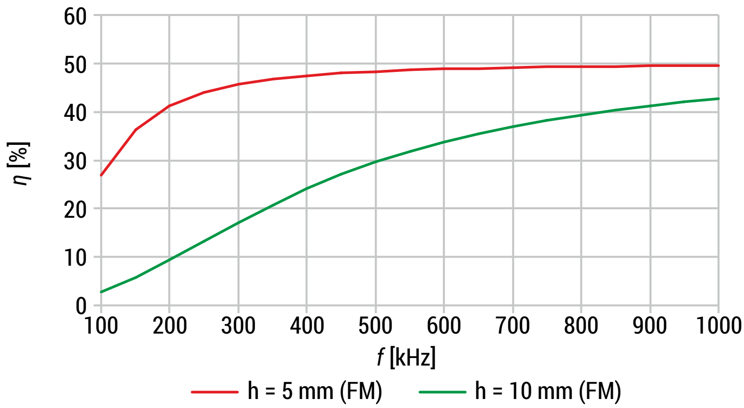

FIGURE 9.9. Results comparison of power transfer efficiency depending on the distance *h* (*n_t* = 30)

The transmitter power P_z decreases over the entire frequency range, regardless of the number of turns *n_t* and distance *h* (Figs. 9.4, 9.7). The power P_z is higher at the distance $h = r = 10$ mm than at $h = r/2 = 5$ mm.

At the distance $h = 5$ mm, the characteristics of receiver power P_o began to stabilize after exceeding a certain frequency (Figs. 9.5, 9.8). At the distance $h = 10$ mm, it was noticed that the maximum receiver power P_o began to stabilize at frequency at least equal to 1 MHz. On the other hand, the values of power P_o were smaller than at the distance $h = 5$ mm.

At the considered operation mode (maximum load power), the efficiency of the system tended to max. 50%. The exception was higher distance ($h = 10$ mm), where maximum efficiency was reached above 1 MHz (Figs. 9.6, 9.9).

Conclusions

The article presents the solution of the WPT system through the use of square planar coils forming both the transmitting and the receiving plane. The proposed solution can be used for charging and powering low-power systems. It can also be used as a charging device for multiple receivers.

The presented numerical approach allows to reduce the number of degrees of freedom by using the WPT cell and periodic conditions.

The numerical solution presented in the article allows to study the influence of the number of turns and the distance between the transmitter and the receiver in a wide frequency range on power transmission.

Thanks to the simple adjustment of the number of turns and increasing the frequency of the current, without the use of intermediate coils, it was possible to obtain the maximum power and the corresponding efficiency of the WPT system.

By means of an appropriate selection of load impedance, it was possible to determine the maximum power transmitted to the receiver and the appropriate efficiency. The results showed that the analysis of an extensive grid of periodic resonators can be numerically simplified to a single WPT cell.

Streszczenie: Artykuł zawiera analizę wpływy liczby zwojów i odległości między płaszczyzną nadawczą i odbiorczą, jak również wynikającej z tego mocy i sprawności dla systemu z bezprzewodowym przesyłem mocy (WPT). Każda z płaszczyzn zawierała planarne cewki kwadratowe o takiej samej geometrii. W artykule zaprezentowano numeryczne podejście do analizy tego typu układów. Celem przedstawionego rozwiązania jest szybkie określenie parametrów wyjściowych (np. moc, sprawność) bez konieczności wykonywania eksperymentów. W analizie uwzględniono zmienność: liczby zwojów, odległość między cewką nadawczą i odbiorczą oraz częstotliwość źródła energii. Wyniki dotyczyły odpowiedniego doboru impedancji w celu uzyskania maksymalnej mocy układu. Uzyskane wyniki pozwalają na szczegółowe omówienie zależności sprawności i mocy układu WPT od geometrii cewek kwadratowych. (Wyznaczenie maksymalnej mocy systemu WPT poprzez odpowiedni dobór impedancji).

Słowa kluczowe: bezprzewodowa transmisja energii (WPT), pole magnetyczne, metoda elementów skończonych (FEM).

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Author: mgr inż. Jacek Maciej Stankiewicz, Bialystok University of Technology, Faculty of Electrical Engineering, Wiejska 45D, 15-351 Białystok, E-mail: j.stankiewicz@doktoranci.pb.edu.pl, ORCID: 0000-0002-1757-2203

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